DIGEST OF INDUSTRIAL AND TECHNICAL DEVELOPMENTS

New Direct Steelmaking Process

IN view of the fact that Bessemer first announced his method of making steel to the British Association exactly a century ago, it was altogether appropriate that the title chosen by Sir Charles Goodeve (who is director of BISRA) for his presidential address to the B.A.'s chemistry section at this year's Sheffield meeting should have been "Steelmaking since Bessemer". The most newsworthy item in his lecture was his mention of the new Cyclosteel process.

The essence of this process is as follows. The finely powdered ore is pre-heated, preferably in a fluidised bed to a temperature just below where it becomes sticky, and then injected into very hot reducing gas. The latter is produced by a fuel such as pulverised coal or atomised fuel oil with only sufficient air and oxygen to partly burn it. From preliminary trials it is known that the two reactions—ore plus carbon monoxide going to iron plus slag and carbon dioxide, and coal plus oxygen and carbon dioxide going to carbon monoxide—are fast with finely divided particles and only a short time in the reaction zone seems to be necessary. The separation of the gas from the precipitated products will take place by gravity and cyclonic centrifugal action, and a settling chamber finally separates the iron from the slag.

The Cyclosteel process, which is being actively developed by the British Iron and Steel Research Association, is still in its very early stages. Sir Charles expressed the view that, in spite of all the modern techniques and resources that are available it is likely to take rather longer than it took Bessemer to make the process a practical proposition. "Cyclosteel" lies on the same line of evolution as the H-iron process (described in the July 12, 1956 issue of *Iron Age*), in which powdered ore in a fluidised bed is reduced by high-pressure hydrogen cheaply produced from oil or hydrocarbon gas.

"Cyclosteel" : One major Problem

WE were interested in the comments which a leading Sheffield metallurgist made on the process. He said that of all the processes of direct steelmaking now being studied Cyclosteel's demands on constructional materials are likely to be greatest of all, since it envisages large masses of gas laden with liquid droplets of iron or iron ore rushing around through pipes at really high temperatures. His own company is also worried because linings of their blast furnaces which make over 1000 tons per day of iron only last a couple of years. The difficulty in the early stages of Cyclosteel may well be to produce linings that may last even a few weeks. The modern blast furnace, he said, produces metal at about a penny a pound, and any rival process would have to reach a very high standard of efficiency before it could compete.

Naturally steelmaking figured prominently in the British Association programme. Many members took the opportunity of visiting local steel works, and other excursions covered the Swinden laboratories of United Steel, the BISRA laboratories in Hoyle St., Sheffield and the Metallurgical laboratories of Sheffield University. A party of 35 chemists visited the works of United Coke and Chemicals, where pure tar acids, phthalic anhydride and maleic anhydride are manufactured. One of the most interesting technical films that were shown during the meeting was the 16-minute colour film made by the Research and Development Department of United Steel showing the pilot plant at Barrow for the continuous casing of steel. The excellent book entitled *Sheffield and its Region: A Scientific and Historical Survey* and edited by Prof. David L. Linton (which the British Association publishes at 24s.) contains a first-rate section on steelmaking and engineering. It also contains many interesting facts about such things as research in the Sheffield area and the industrial development of Scunthorpe (now producing 11% of the total steel tonnage made in the United Kingdom).

Brittle Fracture

ONE of the biggest risks with large welded steel structures is that due to "brittle fracture", and a paper on this subject was given to the British Association by a Leeds University metallurgist., Dr. N. J. Petch. He said that over a fifth of the 5000 welded ships made during the last war in the U.S.A. suffered serious cracking inside two years. Other serious failures have occurred in oil storage tanks and natural gas pipelines. Brittle fractures a mile long have been reported in 30 in. diameter pipes. Moreover this type of fracture can travel at a velocity approaching that of sound: a mile-long fracture can form in about one second. Considerable work has been done on the mechanism of brittle fracture and some understanding of the phenomenon has been achieved.

Dr. Petch pointed out that the association of welding with the catastrophic failures is merely due to the fact that the widespread use of welding has produced large continuous structures, so a brittle crack starting from one source can spread right through the whole structure. With the older riveted construction, such a crack would only spread to the edge of a plate and would then run into free air. The stress concentrations which lead to this trouble seem to be connected with local imperfections or dislocations within the metal. Without them, the metal would be about a thousand times stronger than it is.

New Polymers from Butadiene

THE last I.C.I. annual report stated that a plant was being erected at Wilton by the Plastics Division, which will be capable of producing about 10,000 tons a year of butadiene copolymers. This plant will be operating before the year is out, taking butadiene from the C4 gas stream from the Wilton oil crackers. These copolymers will be sold under the trade name of "Butakon." Initially the range will consist of polymers produced by condensing butadiene with

one of three materials—styrene, methyl methacrylate and acrylonitrile. "Butakons S" is the term applied to the styrene copolymers; similarly the other categories of polymers are known at Butakons M and Butakons A.

The Butakons A combine the flexibility of natural rubber with resistance to swelling and weakening by oils. These synthetic rubbers can be used for making flexible fuel tanks, oil seals and oil-resistant hoses. Marston Excelsior are already using Butakon for the first mentioned application.

The first materials to be produced in the Butakon S series are S8551 and S7001; the first two numbers indicate the percentage of styrene in the copolymer (i.e. 85% and 70%) and the last two numbers identify the manufacturing recipe. Both are supplied as powders. They both possess the property of being able to stiffen or reinforce ordinary rubber compositions. Rubbers reinforced in this way have good tensile strength, hardness, flex life and abrasion resistance. In the U.S.A. about 40% of all shoe soles are made with the aid of these butadiene copolymers. Such soles have the appearance, stiffness and feel of leather and can be worked on standard shoe-making machinery; their life is claimed to be three or four times as long as that of leather soles. The copolymers containing around 40% styrene are considered most suitable for paint applications. In the U.S.A. over 90% of emulsion paints are based on butadiene-styrene emulsions, but the novel latices based on butadiene-methyl methacrylate are a very attractive proposition for paint manufacture, keeping both colour and gloss on ageing. The British literature on these materials is scanty, but the August 1956 issue of *British Plastics* gives some useful information about them.

Synthetic Rubber in India?

STRANGE as it may seem, the Government of India are seriously considering the establishment of a synthetic rubber plant. In spite of the abundance of natural rubber in that part of the world, it is expected that the synthetic material will actually be cheaper to the extent of approximately 3d. per lb. The plant, it is estimated, would cost about £10 million.

Monsanto's Petrochemical Plans

IMPORTANT developments in the manufacture of petrochemicals in Britain have been announced by Monsanto Chemicals Limited. The company plans to spend some £8½ millions on the first stage of a long-term expansion programme. As indicated in the company's report for 1955, a new factory will be constructed on a 100-acre site alongside the Fawley refinery of Esso, from which Monsanto will draw feedstock for conversion into a wide variety of raw materials for use in the plastics, textile, rubber, paint, paper and other manufacturing industries.

The first plant to be erected will be for the manufacture of 10,000 tons of polyethylene a year. Survey work is being carried out on the site, construction will begin shortly and production is scheduled to start in 1958.

The next product in the company's programme will be copolymers of acrylonitrile, butadiene and other monomers. These copolymers have a wide range of uses in the rubber, paint, plastics, paper and other industries. Following this a major plant is to be constructed for the manufacture of acrylonitrile, an important chemical not yet made in Britain.

Britain needs more Chemical Engineers

WE were very glad to see Sir Harold Hartley's article in *The Financial Times* (22.8.56) calling upon industrialists to press for an expansion of chemical engineering training in Britain. He argued that a steady, combined effort by all concerned is needed if the rising demand for chemical engineers is to be met effectively. Sir Harold indicated how industry can assist in this connection. "It can endow chairs and departments, as it has done at Birmingham and Cambridge, it can provide facilities for vacation works courses for chemical engineering students, it can encourage young apprentices to take 'sandwich' courses at technical colleges and organise instruction for the students during the six-monthly periods spent at works," he commented. One important point he raised was this: because of the present good prospects of a career which it offers, some of the many students who at present choose chemistry would be well advised to look towards chemical engineering. The Institution of Chemical Engineers has already done much to make schoolboys aware of the career prospects in chemical engineering. Their excellent careers booklet has already had considerable influence in the schools and we understand that a new edition which should prove even more effective will be published soon.

Convention of Chemical Engineering, 1958

PREPARATORY work in connection with the European Convention of Chemical Engineering (to be held in Frankfurt am Main during the period May 31—June 8, 1958, in connection with the ACHEMA 1958 Twelfth Chemical Apparatus and Equipment Congress and Exhibition) has already produced noteworthy results. The twenty three European technical and scientific societies, which together form the European Federation of Chemical Engineering, will also hold their Second Congress within the framework of the European Convention of Chemical Engineering. This Congress opens in Brussels (May 28—30) and will continue in Frankfurt am Main (May 31—June 8, 1958). The European Federation of Corrosion, to which some forty-five European technical and scientific societies belong, is also planning to hold its Second Congress in Frankfurt am Main. Furthermore, the "Gesellschaft Deutscher Chemiker" (Society of German Chemists) will hold a Special Meeting and DECHEMA will hold their annual meeting during the course of the European Convention of Chemical Engineering. Finally, DECHEMA will conduct an "International ACHEMA Students' Meeting", to which all advanced students of chemistry, physics and engineering as applied to chemical equipment and process engineering will be invited.

No less than thirteen large exhibition halls with a total floor space of 66,000 sq. metres, have been booked for the ACHEMA 1958 Chemical Apparatus and Equipment Congress and Exhibition. Almost all the available floor space has already been taken up by 620 exhibitors, and it seems very doubtful whether all requests for exhibition space at the forthcoming exhibition can be met.

Both the European Convention of Chemical Engineering and the ACHEMA Chemical Apparatus and Equipment Congress and Exhibition are organised and conducted by the DECHEMA Deutsche Gesellschaft für chemisches Apparatewesen E.V. in Frankfurt am Main.

British Oxygen at Farnborough

VISITORS to the British Oxygen stand at the Society of British Aircraft Constructors' Show at Farnborough saw a prototype 3½-litre liquid oxygen converter, specially designed for use in fighter aircraft. Also on view were models of the oxygen demand regulator similar to those which the Company has supplied for use in the Bristol

Britannia. Increased oxygen requirements in modern aircraft have augmented the familiar problem that oxygen cylinders are both heavy and bulky; consequently, the extra weight and space penalties are even more detrimental to aircraft performance. British Oxygen have solved this problem by developing vessels which store oxygen in the aircraft as liquid under low pressure. When the oxygen is required for breathing, it is converted from liquid to gas at normal temperatures.

Weight-saving is also a most important characteristic of the diluter demand oxygen regulators, which were also displayed at Farnborough. The oxygen diluter demand principle of the regulator ensures minimum oxygen consumption, reducing the number of weighty oxygen cylinders that aircraft have to carry.

British Oxygen also showed the Argonarc welding process, with its range of specialised torches for engine and airframe construction. Notable advances made in the welding of jet engine components have been due in large measure to extensive use of this welding method, the only process suitable for the fabrication of heat-resisting steels, nickel, and other alloys now widely used in jet engine construction. New alloys and metals, such as titanium, will be increasingly used for both engine and airframe construction and the ability to weld these metals by the Argonarc process will give impetus to these developments.

Also displayed on the British Oxygen stand were precision die castings used in aircraft oxygen equipment. In addition to the indoor exhibit, 50 and 500 gallon liquid oxygen refuelling tanks were shown outside, and demonstrations of converter refuelling were given. The 50 gallon tank is trailer-mounted to facilitate airfield servicing operations.

U.S. Companies in Britain

AMERICAN firms now control a significant fraction of the industrial production of Britain. Some eight hundred U.S. companies are now operating in Britain, in lines which include chemical and pharmaceutical production, oil refining, and the manufacture of regulating instruments, carbon black, synthetic detergents and soluble coffee. Since 1945, American companies in Britain have invested roughly $1000 million, the bulk of it by ploughing back profits made in Britain. After allowing for some repatriation of capital, this postwar investment has brought U.S. net investment in Britain to nearly $1400 million—or about 7% of all U.S. direct investment overseas. Heavy manufacturing absorbs 32% of the workers employed by American firms; motor vehicles, 24%; chemicals (including oil refining and pharmaceuticals), 13%; industrial and scientific instruments, 7%; food, drink and tobacco, 7%; electrical products, 6%; and miscellaneous manufactures, 11%.

Wanted: Staff for Technical Colleges

IN our August leader ("Raising a Revolutionary Army," p. 187), we mentioned the need for the Government to take steps to recruit and train more technical teachers; as the F.B.I. memorandum on the White Paper on Technical Education remarked, plans for recruiting and training them are every bit as important as the capital investment plans announced by the Government.

The Minister of Education has taken note of this point and has set up a committee which will advise *urgently* upon the recruitment and training of teachers for technical colleges. Members of the committee have been nominated by the chairman of the National Advisory Council on the Training and Supply of Teachers and by the chairman of the National Advisory Council on Education for Industry and Commerce. The committee's chairman and vice-chairman are respectively Professor Willis Jackson (director of Research and Education Metropolitan Vickers Electrical Co. Ltd.) and Councillor R. McKinnon Wood of the London County Council. The other members of the committee are Dr. F. Briers, Sir Hugh Chance, Alderman C. B. Jones, Mr. D. R. Mackintosh, Miss Anne Shaw, Mr. J. G. Docherty, Mr. A. E. Evans, Mr. H. Wyn Jones, Prof. R. A. Oliver, Mr. E. W. Woodhead, and Mr. A. Maclennan.

Irradiated Polythene

PLASTICS parts fabricated from irradiated polythene (filled with carbon black) are now being made available by the Chemical Development Dept. of General Electric's Chemical and Metallurigcal Division Pittsfield, Massachusetts. Known at Vulkene 107-E vulcanised reinforced polythene, this new material is a black tough, flexible plastic with physical properties, heat and chemical resistance reportedly superior to conventional high-pressure polythene, from which it is derived. The yield strength at low temperature for Vulkene 107-E is said to be double that of polythene and creep deformation is reduced to approximately 10% of the value obtained for polythene.

Due to its cross-linked structure, Vulkene 107-E can be carried to its decomposition temperature without melting. At 300°F it retains a tensile strength of 500 psi. Its excellent heat stability has been demonstrated in long-term exposure tests in hot air and boiling water. Other significant properties cited are outstanding chemical resistance and resistance to inorganic acids, and elimination of stress corrosion cracking.

Due to its high carbon-black loading, Vulkene 107-E reinforced irradiated polyethylene is electrically conductive. General Electric is about to test-market a modification of the material as semi-conductor tape in shielded power cable. Preliminary evaluations are said to show excellent promise for this application. In tape form, this material is also sold under General Electric's trademark Irrathene (R) irradiated polyethylene. This is a special electrical grade of polythene, which is rendered non-melting by electron irradiation. It offers high-temperature stability and has found early application in motor insulation and in communications cable, as well as in switch gear insulation.

Commercial success of this new tape is indicated by the fact that the company which manufactures the irradiated tape at its Pittsfield, Massachusetts headquarters, recently doubled capacity of its manufacturing facilities.

Titanium from Rutile

BRITAIN is well ahead with the production of titanium, and the metal which I.C.I. turns out is the cheapest in the world. After the aircraft industry takes its requirements there is however little British titanium to spare for any other applications. To some extent the expansion of titanium output depends on finding large deposits of rich ore. Australia has been providing rutile, the dioxide of titanium which is found in igneous and metamorphic rocks. Of recent years the search for new rutile deposits has been intensified, and 1955 saw a substantial increase in the Australian output from beach sands. The U.S.A. is tapping Mexican sources of this mineral.

Intensive prospecting in West Africa has recently brought to light in Sierra Leone vast deposits of low-grade rutile, contained in a series of ancient marine sediments. Plans for the exploitation of these, together with certain highly enriched off-shore deposits, are now well advanced. Although full details have not yet been made

available, we are given to understand that the recovery of the rutile and associated minerals from the highly plastic clays has presented difficult problems. It is believed that the operation will consist of a combination of dredging and open-cast mining methods

Apart from its occurrence in Sierra Leone, rutile from the French Cameroons, was at one time in strong demand. Production, which started in 1935 and grew to a peak of 3320 tons per annum in 1944, was reported to have ceased entirely in 1954, due to the exhaustion of the alluvial deposits which had hitherto been worked by primitive means. According to a recent report the French Government has assembled an expert team to explore and assist in the development of this still potentially productive field. The Cameroons rutile aroused great interest amongst mineral buyers because of its marked superiority to Australian ore. While most specifications called for a concentrate containing not less than 92% TiO_2 and not more than 3% Fe_2O_3, 2% Al_2O_3, 2% CaO and 1% ZrO_2 (besides fine limits for phosphorus sulphur and silica), the Cameroon ore averaged better than 98% TiO_2 and less than 1.7% Fe_2O_3 according to one source, and better than 97.5% TiO_2 and less than 1.3% Fe_2O_3 according to another.

Since both British and French geologists appear to agree about the derivation of the rutile from shear zones in gneiss near the granite contact, it is possible that this superior grade may also be found in Sierra Leone. If this should prove to be the case and having regard to the immense tonnages available only some 2830 miles distant from U.K. ports, West Africa may eventually become the leading world producer of rutile.

India's Industrial Revolution

THE recent visit which Mr. Stephen Garvin paid to India has resulted in a 50-page report published by the F.B.I. under the title *India: A survey for British Industrial Firms*. India, of course, stands high on the list of Britain's best customers, and last year she took £130 million worth of our goods. The Indian Government's first five-year plan brought about an increase in the national income of 18%. The second five-year plan will require the importation of machinery and equipment worth about £1000 million. It is anticipated that during this second five-year period (1956-61) a further increase in the national income of 25% is well within the bounds of possibility. Mr. Garvin disagrees with those who regard these plans of the Indian Government as political manifestos rather than serious economic blue-prints, a view which he considers no one who has recently visited India and seen what has already been accomplished could share.

Targets for Chemicals and Steel

THE report lists the targets which the Indian Government has set for some of the major industries. By 1961 India aims to be producing 470,000 tons of sulphuric acid, 230,000 tons of soda ash and 135,400 tons of caustic soda. Big increases in fertiliser output are also planned. As a symbol of what has already been achieved Mr. Garvin cites the case of the Sindri Fertiliser Factory. This produces 350,000 tons of ammonium sulphate a year, and is now to be extended for the production of 70 tons of urea and 400 tons of ammonium sulphate/nitrate per day. (The contract for the extension went to Italy's Montecatini.)

The target for iron and steel production is based on the doubling of the capacity at the existing plants of the Tata Iron and Steel Co. Ltd. and the Indian Iron and Steel Co. Ltd., and the erection of three new Government-owned steel plants. The latter plants are to be built with technical help from three different countries—from Western Germany (Rourkela plant), Russia (Bhilai) and Britain (Durgapur). The total cost of the Durgapur plant will be about £50 million, and this contract is claimed to be the largest ever placed with a British company—actually a consortium of firms, registered as the Indian Steelworks Construction Co. Tata has plans to increase output very considerably; in line with the Tata tradition it has gone to the U.S.A. for technical aid, but it has ordered equipment from Germany and Japan as well as from America. The other private steel enterprise has placed contracts in Germany and the U.K. for equipment required in the expansion of its Burnpore and Kulti plants.

£48 million Steel Expansion

THE Steel Company of Wales has given details of its plans for expansion recently approved by the Iron and Steel Board. Under this plan the present capacity at the Abbey Works (the largest in the United Kingdom), 2.4 million tons per year, will be raised to 3 million tons by 1960. The expansion scheme is at present estimated to cost £48 million. For some time there had been speculation concerning the establishment of a completely new thin sheet mill at a fresh site. In the light of current difficulties in the motor trade the decision to expand at Abbey seems to be a satisfactory half-measure to increase the home production of thin sheet.

The chairman of Woodall-Duckham, Ltd., has announced that the company have obtained a substantial contract for further coke ovens to be built for the Appleby-Frodingham Steel Company, one of the United Steel group. The contract is for 66 new ovens, which will have a throughput of 9350 tons of coal per week. This installation will be an extension to the existing 132 Koppers type ovens which turn out, in addition to coke, some 150,000 gallons of tar per week, 225 tons of sulphate of ammonia, and 72,000 gallons of crude benzole.

The Cheapest Steel in Europe

REPORTS now available on the steel industry's performance for 1955 show Germany as the largest producer with 21.3 million metric tons, followed by the U.K. with 20.1 million, and then France/Saar with 15.8 million. These three countries account for some 72% of the output of the OEEC members.

Each country has its peculiarities. The U.K. consumes about 85% of its output, and, with Sweden, has the highest consumption per head, although this is only about half the U.S.A. consumption per head of about 12 cwt per year. The British production is 82% accounted for by basic open-hearth furnaces. About half of the ore used is imported, the remainder being lean local ore. The British steel industry uses a higher proportion of scrap (some 37%) than any of the other countries, with the exception of Italy. In 1955 the U.K. maintained its position as the cheapest producer in the European community, with France as runner-up. All the British prices showed up well compared with the U.S.A., except in the case of hot-rolled thin sheet. The most advantageous British product was heavy plate.

The industries in Austria and Sweden have attracted much technical interest. In the former country the L-D process, which makes steel in a converter by downward blowing of oxygen, is now responsible for 37% of the output. In Sweden over 25% of the production is of special steels, and the iron is made by a variety of methods aimed at needing only small quantities of imported fuel.

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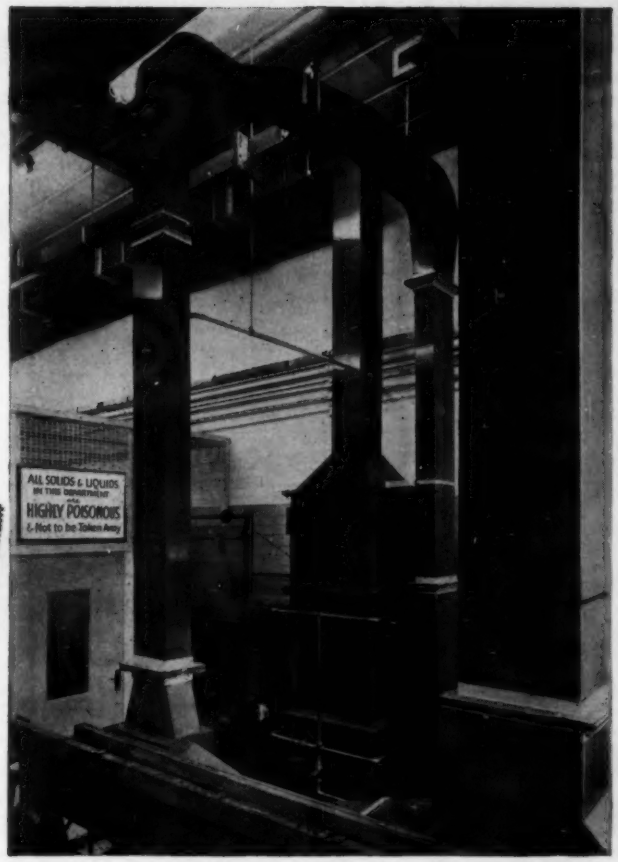

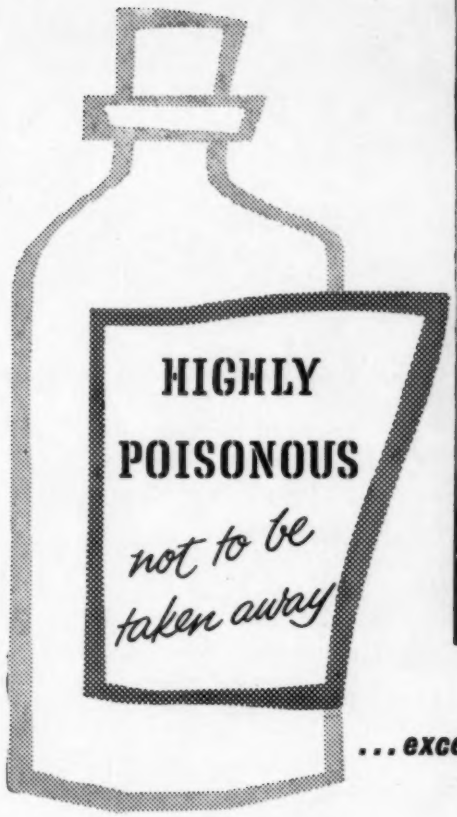

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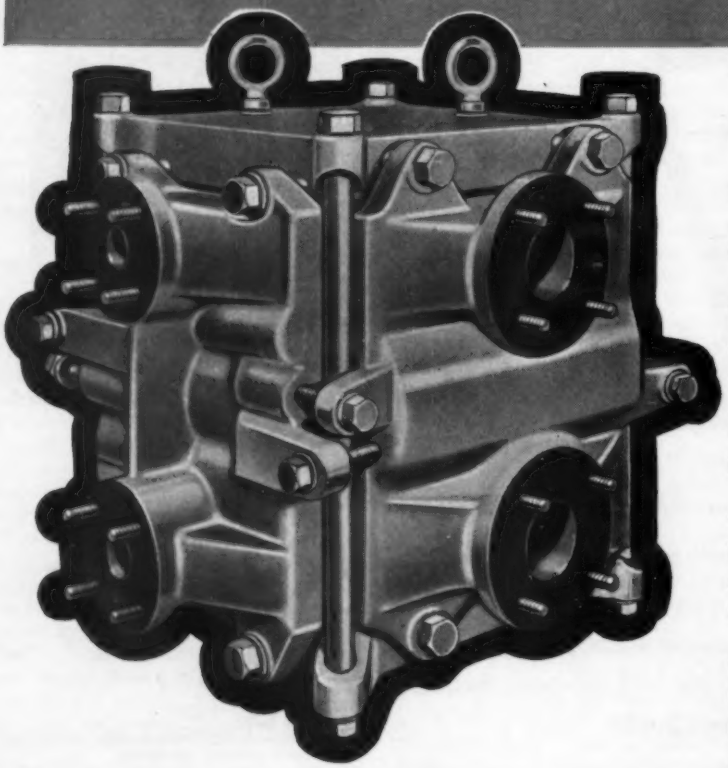

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Balancing Britain's Fuel Budget

THE drive for the more efficient utilisation of fuel was born of wartime necessity, and it has been maintained ever since because of the continuing coal shortage. British industry has had to take this factor into account throughout the post-war period, and on the whole it has risen to the challenge magnificently. Many an industry can quote with pride the increased output that has been achieved per ton of coal consumed, but fuel supplies are still restricted and the drive for greater fuel efficiency must go on.

This is the context of the fuel efficiency exhibition to be held at Olympia this month. Some 150 firms will be showing equipment relevant to fuel economy in all branches of industry, and the exhibition will be backed up by a technical conference that will discuss such important topics as the efficient use of coal and oil, NIFES (National Industrial Fuel Efficiency Service) heat and power surveys and waste heat recovery. The exhibition is bound to prove a worthy successor to the exhibition which NIFES and the Combustion Engineering Association organised in Manchester last year.

One of the remarkable things is that the fuel efficiency campaign seems to be gaining momentum rather than the reverse. It began fifteen years ago, and it would not be surprising if by now enthusiasm for the campaign began to dwindle. It looks, however, as though the crop resulting from seeds planted during that period will go on being harvested for a long time to come. There are no signs yet that the law of diminishing returns has started to operate, and this is a feature of the campaign which is most impressive.

More and more firms are taking advantage of the service provided by NIFES, which came into being at the end of 1953. This organisation recently carried out its thousandth heat and power survey. This particular investigation (made in one of the paper mills run by Albert E. Reed & Co. Ltd.) typifies an approach to fuel economy which is paying big dividends. There is nothing spectacular about the way in which NIFES experts find out what happens to the heat and power consumed in a factory. This is routine work, but from the interpretation of the instrument readings which are taken in factories all over the country can come a saving of a further 10 million tons of coal a year. In the particular paper mill mentioned above the coal consumption per ton of paper produced has fallen from about 22 cwt to 12 cwt in a matter of ten years. It costs money to achieve a reduction in coal consumption of that order, but the firm finds that it is very much worthwhile, though the cost of the coal used in the mill represents no more than 8% of the total manufacturing cost. Obviously a firm will only spend money to achieve greater fuel efficiency where it is financially worth while. It would obviously be ridiculous for any profit-making organisation to take fuel-saving measures regardless of cost, though there are some publicists who ignore that point altogether and preach blithely about how Britain could save 50 million tons of coal a year! What British factories can achieve is the kind of fuel economy practised in such plants as Reed's paper mills. That way the country can effect savings to the tune of 10 million tons of coal, and that would go a long way towards balancing Britain's fuel budget.

In the immediate future there seems little hope that supplies of coal will become more abundant. The trend towards the increasing use of oil is therefore likely to be maintained, even though the Suez crisis has made everyone aware that greater reliance on oil carries with it serious strategic risks. Conversion to oil has been encouraged by the Government Loan Scheme which was introduced in 1952. NIFES second progress report gives figures showing how this is catching on; within a year 238 oil-conversion schemes were approved which offered a total coal saving of over 200,000 tons. Just over £1 million was advanced as loans for these schemes. NIFES is now organising special intensive courses on oil firing, and these are raising the general level of practice throughout industrial firms. The day when the untrained stoker could waste as much fuel as a trained miner can win is practically gone, which is no small advance. In the present situation NIFES is a valuable national asset, and will remain so as long as Britain is short of fuel and power. We hope that its activities never need to be restricted for financial reason; there is general agreement that the money spent on NIFES is a first-class investment, and we are glad to know that the present Minister of Fuel holds that view.

One particular aspect of fuel efficiency is immensely topical at the present time. In the past, when Britain enjoyed a superabundance of cheap coal, the belching of smoke from factory chimneys was almost a symbol of the country's industrial prosperity. Only an informed minority regarded it as a symbol of fuel wastage. Public opinion has altered violently of recent years, and now this year the Clean Air Bill will become law. From now on it will be a crime to create unnecessary and avoidable smoke. What the new law on atmospheric pollution will mean to industrialists is one of the subjects to be discussed at the Fuel Efficiency Conference associated with the Olympia exhibition. Most appropriately, the chairman for that session will be Sir Hugh Beaver, who presided over the Air Pollution Committee upon whose report the Government based its anti-pollution legislation. We find it an encouraging thought that greater fuel efficiency makes for less atmospheric pollution. The Industrial Revolution brought a blanket of grime and filth to many parts of Britain, but now we can begin to glimpse the reappearance of clear skies and green land in a new era in which the chimney with no smoke will be the symbol of efficient production.

Guide to the Selection of Pumps for the Chemical and Process Industries

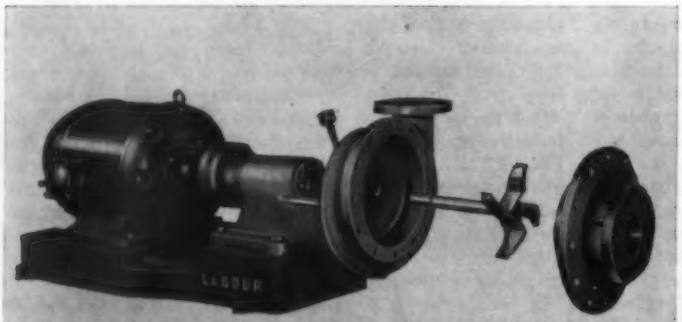
by J. O. S. MacDONALD, B.Sc., A.R.I.C., A.M.I.Chem.E.

THE problem of selecting a pump suitable for a given duty contains many variables, all of which must receive their proper attention if a successful installation is to be effected. First one may have to determine whether the materials to be transported can be handled by a pump or whether some other means of transportation is not more suitable. Secondly arises the problem of finding the best type of pump for a particular task; thirdly is the associated problem of installation; and, finally, there are the features of mechanical design such as gland or shaft-sealing arrangements which affect selection.

An outline of the types of material that can be pumped and the working conditions under which the pumps operate casts some light upon the scope of the pumping process. Both in terms of materials and conditions, particularly temperature and fluid viscosity, the field currently covered is an extremely wide one. Materials may range from powdered solids rendered fluid by a small quantity of compressed air, they may be slurries containing as much as 70% of solids by weight, or they may be clear fluids containing solids of much greater dimensions than the term "slurry" implies. Fluid viscosities may vary from the low values encountered with liquefied gases to values as high as 10,000 centipoises. Temperatures can vary from the boiling points of liquefied gases such as liquid oxygen (around the −180°C mark) to temperatures in the region of 750°C when the pumped material may be a molten salt. The tendency to extend the temperature range of pumping operations is increasing, and nowadays it is quite usual to find materials like molten metals being successfully pumped. The use of molten sodium in heat-transfer systems is such an example. Today, the liquids or molten solids that are being handled by pumps vary considerably in their corrosive properties, some of which have given rise to some formidable problems of mechanical design. In some instances the fluids handled are used in nuclear processes and they may be emitters of neutrons. The latter destroy normal pump-packing materials so that special shaft-sealing problems arise. In other cases the fluids pumped are hazardous in terms of toxicity or flammability and here also special care has to be taken to conserve the fluid within the pump.

Many problems arise where the materials to be transported appear to be pumpable but involve special difficulties which can only be resolved by experiment and trial. A crystalline slurry which has to be pumped without breaking the crystals down into smaller particles or a viscous fluid which has to be transferred under conditions where the pressure is close to its vapour pressure are problems of the kind which may require practical trials before a solution is found.

It may prove that when all the usual methods of pumping have been investigated that the best solution does not involve a pump. The problem may, for example, be best solved by means of a conveyor or by transportation in closed cylinders to the point of use. Again, the best answer may be that of evaporating the liquid, followed by compression and condensation at a higher temperature. Such solutions, especially the latter, may prove to be expensive in first and operating costs. The first point may therefore be to decide that the pump is the answer to the problem. Where there is uncertainty on this point, which



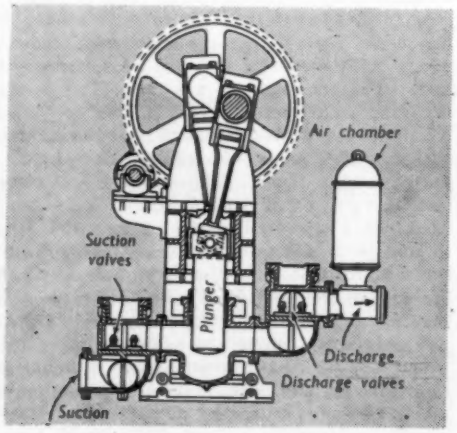


Fig. 1 (above). A centrifugal pump for chemical service (British LaBour). Fig. 2 (right). A reciprocating pump of the plunger type.

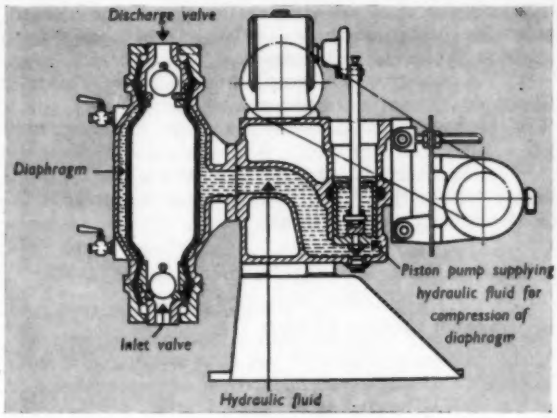


Fig. 3. Hydraulically operated diaphragm pump (Merrill Pumps Ltd.).

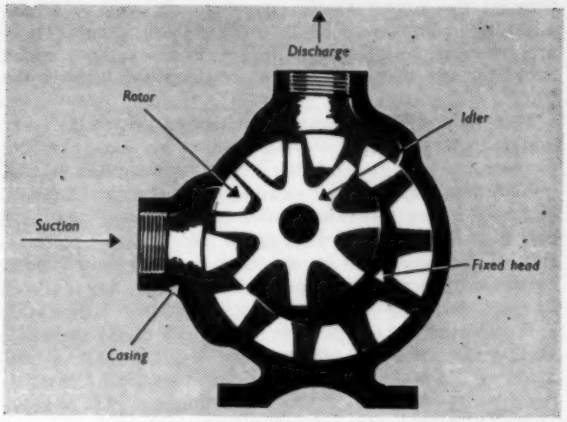


Fig. 4. Rotary pump for clear non-corrosive liquids (Wayne Tank and Pump).

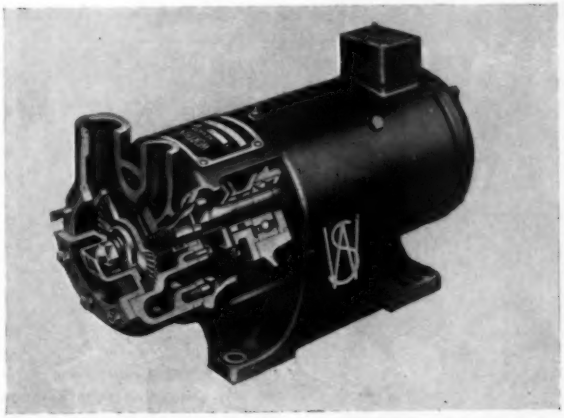


Fig. 5. Peripheral pump—a low capacity self-priming pump (Worthington-Simpson).

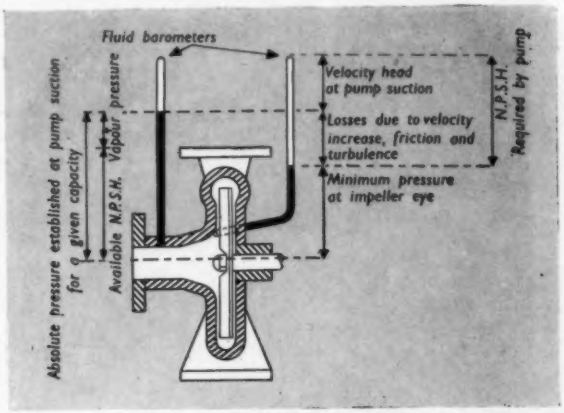

Fluid barometers
Velocity head at pump suction
Losses due to velocity increase, friction and turbulence
Minimum pressure at impeller eye
N.P.S.H. Required by pump
Absolute pressure established at pump suction for a given capacity
Available N.P.S.H.
Vapour pressure

Fig. 6. A diagram illustrating the NPSH concept.

may be the case where new ground is being broken, then the following discussion may help in the selection of the best unit for initial experiment.

Classification of Pumps

(1) *Centrifugal Pumps*
- (a) Radial flow horizontal.
- (b) Vertical.
- (c) Glandless.
- (d) Self-priming.

(2) *Positive-displacement Pumps*

(2A) Reciprocating Pumps
- (a) Piston.
- (b) Plunger.
- (c) Diaphragm.

(2B) Rotary Pumps
- (a) Gear, Lobe, etc.
- (b) Vane.
- (c) Screw.

(3) *Peripheral Pumps*

Such a classification gives the impression of an exhaustive procedure, in which each type and grouping is examined for its suitability for a given duty. In practice, a much simpler method is used. In the first place the possibility of using a centrifugal is examined closely, and if a case for the centrifugal is indicated then it is chosen in preference to other types which may also be able to handle the given fluid. There will be very many instances, however, in which the centrifugal is the only choice. In the classification no mention has been made of special pumps, such as compressed-air-operated pumps and electromagnetic pumps. These will be covered in a future article dealing with unusual pumping techniques.

Centrifugal Pumps

In pumps of this type a rotating impeller imparts a high velocity to the fluid being pumped. The cross-sectional area of the fluid channel at the periphery of the impeller increases gradually to the discharge connection on the pump casing, with the result that the fluid velocity is converted to pressure. The head developed by such pumps is thus a function of the fluid velocity and for a given speed of impeller the head developed will be independent of the specific gravity of the liquid being pumped, the suction conditions allowing the pump to function normally.

Valuable features of centrifugal pumps are the steady flow of liquid they produce, their ability to permit variation by throttling, a feature which makes them useful for systems employing automatic control of flow. Mechanical advantages are their simplicity, the absence of valves and of extensive rubbing surfaces. The latter are found only at the gland or shaft seal where the driven shaft passes

through the casing to the impeller, but this is a disadvantage common to all types of rotating pump. There are, however, centrifugal-pump designs in existence which avoid the use of glands; these are described later in the text.

The main operating characteristics of centrifugals are that reduction in head is accompanied by a considerable increase in capacity, and that power consumption is at a minimum at closed discharge and increases with a decrease in head. Where a constant delivery is required against a variable head, a variable-speed drive is necessary. Efficiency as measured by the work done on fluid divided by the work done on the pump is as low as 5% for very small capacity pumps, but for large units efficiencies approaching 90% are possible. Capacities of pumps available in this country are as high as 3000 gpm against heads of 200 ft or more. Typical fluids handled by centrifugal pumps include slurries containing as much as 70% of well-dispersed solid matter[1] and clear liquids at elevated and sub-zero temperatures.

Since the preliminary choice will generally be a centrifugal, its limitations have an important bearing upon selection. The fluid limitations are:

(a) Viscosity must not exceed about 15 poises. This limit is affected by the size of pump, as shown below.

(b) Undissolved gases or air should not be greater than 5%.

In connection with the first limitation, the following figures were obtained from a manufacturer's publication.[2]

Maximum viscosity (poises):					
0.3	0.5	0.8	1.0	2.0	3.0
Smallest pump. Size in inches (outlet bore):					
¼	1	1½	2	3	5
Maximum viscosity (poises):					
4.0	5.0	6.0	8.0	9.0	20
Smallest pump. Size in inches:					
6	8	10	12	14	16

As for the second limitation, a few models are now available which can work satisfactorily with as much as

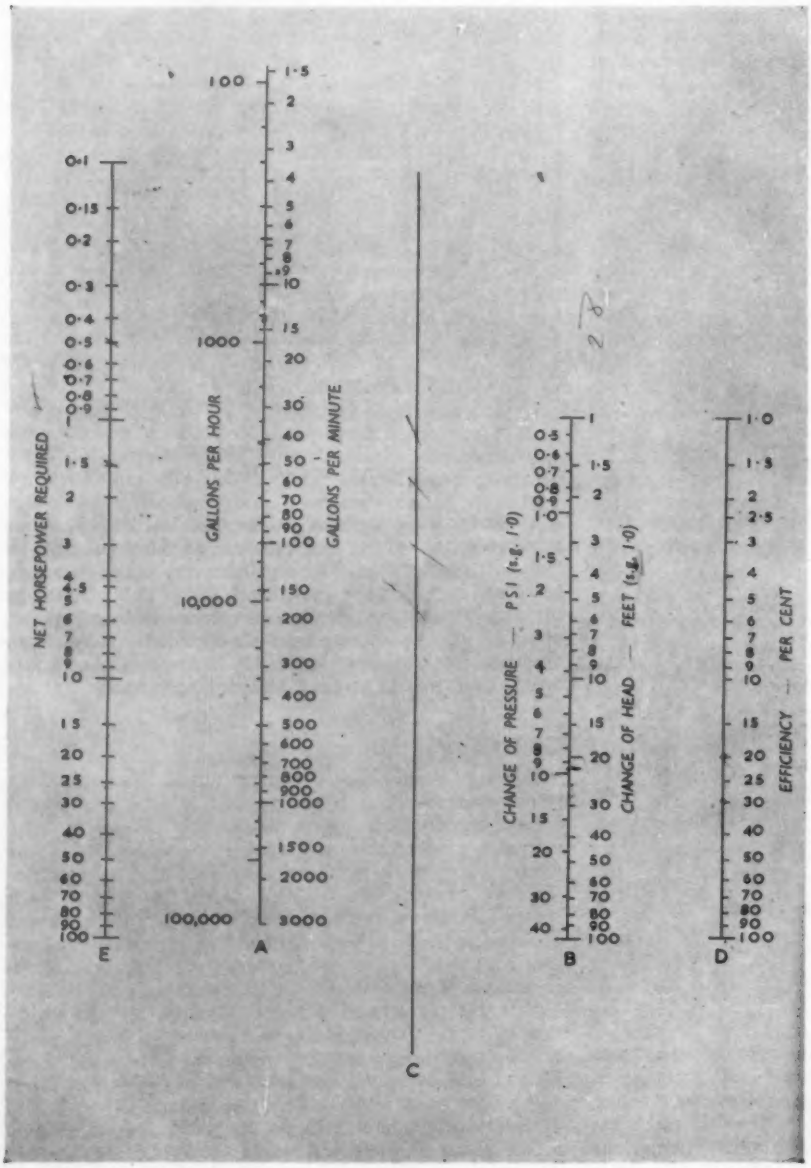


Fig. 7. Nomogram for estimating horse power for various kinds of pump. Set ruler between column A (flow rate) and column B (change of head) to give intersection on reference line C. Positive displacement pumps 90%; Peripheral 80%; Centrifugal large capacity 65%; Small capacity centrifugal 30% or less

20% of entrained gases.[3] Another limitation of the centrifugal is its inability to self-prime, although there are some well-proven designs of self-priming pump available when this property is required.

An advantage not always recognised is the centrifugal's ability to work well under what are known as marginal Net Positive Suction Head (NPSH) conditions. This aspect of pump selection will be discussed later. Finally, and a point worthy of notice, the centrifugal is available in a wider assortment of constructional materials than any other kind of pump.

Reciprocating Pumps

In many pumps of this kind the pumping element is a piston which moves back and forth in a cylindrical casing. A piston stroke in one direction causes a volume of liquid almost equal to the piston swept volume to be drawn through a valve on the inlet side of the pump. Movement of the piston in the reverse direction forces this pocket of liquid, now under pressure, through another valve into the discharge line leading away from the pump.

The discharge characteristic of a reciprocating pump is therefore a pulsating one. A smoother discharge is obtained by designing the pump as a double-acting unit, but although this gives a smoother discharge, pulsations will still occur because the discharge of liquid stops at the end of each stroke. It is common practice, therefore, to install an air chamber on the discharge of such pumps. The air trapped in such a cylinder is compressed with the discharge from the pump. At the point in the piston movement where delivery and pressure begin to fall the air expands and expels a volume of liquid into the discharge lines. This helps to compensate for the reduction in delivery at that point of the cycle and a further smoothing of flow results. These pumps give a constant output under varying heads, and efficiencies are generally in the region of 90%. The pressure developed by some designs rises as high as 1000 psi, with maximum outputs around 2000 gpm. Valuable features of these pumps are their ability:

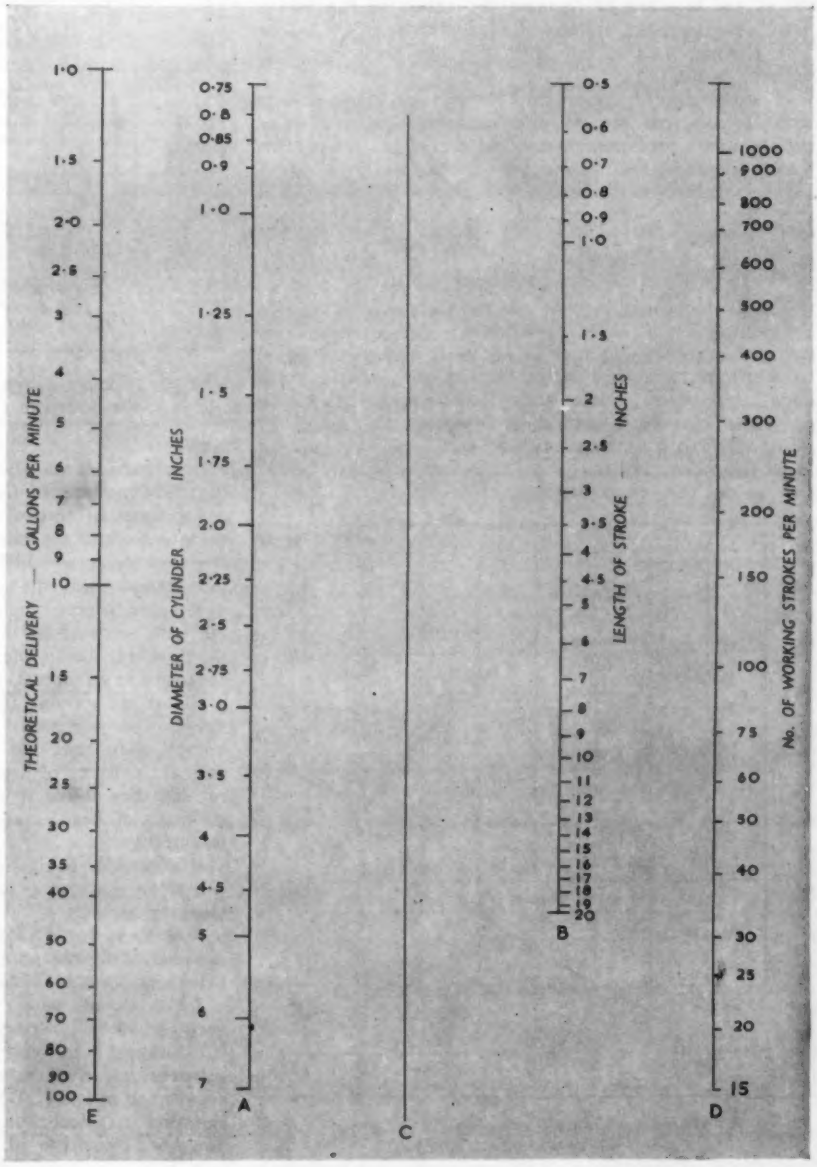


Fig. 8. Nomogram for estimating reciprocating pump capacity. Set ruler between column A (cylinder diameter) and column B (length of stroke) to give intersection on reference line C. Choose number of working strokes on column D and set ruler through reference point on C to give theoretical delivery on column E.

(a) to handle large proportions of vapour;
(b) to self-prime;
(c) to cope with high suction lifts;
(d) to handle liquids with viscosities as high as 10,000 centipoises.

Disadvantages are the presence of valves in the construction, the large space occupied, and the necessity for providing relief valves in the discharge lines for by-passing back to the suction in order to protect the pump when the delivery line is closed. With some varieties the large frictional surfaces may be considered a drawback, but this is frequently exaggerated.

Some of the materials which reciprocating pumps are capable of handling are slurries (plunger and diaphragm), muds, hot oils, as well as clear liquids.

The diaphragm variety, which are included in this grouping, employs a plunger which is attached to the centre of a circular diaphragm. The flexibility of the latter allows it to be moved to and fro by the plunger so that positive displacement is obtained without employing rubbing surfaces. As with the plunger or piston types, valves are required to regulate the action of the pump. Their characteristics are also similar to those of the piston and plunger pumps, but they are not used for high delivery heads.

A number of diaphragm pumps are hydraulically operated, so that the power is delivered from a small piston pump connected closely to the main pump. This avoids attaching the diaphragm to a plunger (Fig. 3). A point in favour of some types of reciprocating pump is that they can be steam-driven.

Rotary Positive-displacement Pumps

These pumps differ from reciprocating pumps in that the pumping is achieved by rotating members within the pump casing. These rotors cause small pockets of liquid to be trapped between the rotors and the casing and the rotating movement transfers the liquid pockets from inlet to outlet. As the classification indicates, the means of doing this varies considerably, i.e., from pumps employing gears to screws.

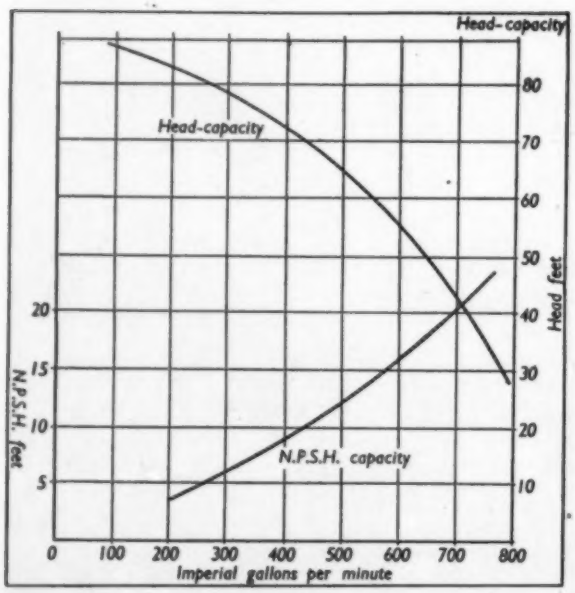


Fig. 9. NPSH characteristics of a typical chemical service pump (Worthington-Simpson).

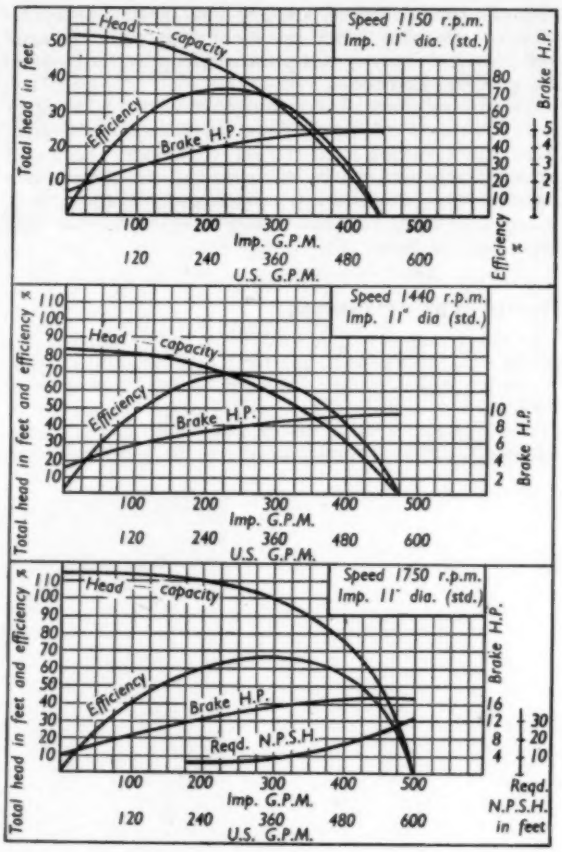


Fig. 10. Typical centrifugal pump curves including NPSH characteristic (Girdlestone Pumps Ltd.).

The operation of all pumps of this kind depends upon the close meshing of the rotating parts, whether they are gears, lobes or screws, and the close clearances between these parts and the pump casing. In other cases, such as the vane type, a rubbing contact is maintained between the vanes and the casing. The flow characteristic in the case of gear-type pumps is a series of minute ripples, but with some of the other types, such as vane or screw, the flow is a steady one. All these pumps are self-priming, are capable of operating successfully under high suction lifts and are suitable for use in pumping from evacuated vessels. In common with other positive-displacement pumps, they give, for a fixed driven speed, an almost constant delivery of liquid under varying head conditions. In this they differ from centrifugal pumps, in which a variation of head is accompanied by a marked variation in capacity.

It is possible to obtain rotary pumps of this kind which will achieve pressures as high as 2000 psi, handle fluids of viscosity as high as 5000 centipoises, can be operated at temperatures approaching 500°C, and can be conveniently jacketed where the application requires the supply of heat to render a material flowable.

The materials which can be handled by rotary pumps vary considerably. They have been employed successfully for pumping tars, pitch, heavy lubricating oils, diesel oil, kerosene, toluene, carbon tetrachloride and so on. They are sometimes useful where it is desired to avoid the agitation that occurs in a centrifugal pump. Such pumps, however, by virtue of their close clearances and inter-

meshing parts, are limited generally to fluids which:

(a) do not contain solids;
(b) are non-corrosive;
(c) have lubricating properties.

Further mechanical disadvantages are their inability to be operated against a closed discharge, thereby necessitating a by-pass valve for transferring liquid from the delivery back into the pump inlet.

There are exceptions, however, as some forms of screw pump, particularly those manufactured according to the Moineau patents,[4] are able to handle coarse and abrasive solids successfully. But high-temperature applications are not practicable with this type of rotary pump since a stator is generally employed which is not temperature-resistant. Some varieties of sliding vane pump are also able to handle fluids containing abrasive solids, but a careful selection of materials of construction in such instances is necessary.

Peripheral Pumps

With these pumps a rotor develops head by recirculating the liquid through a series of rotating vanes. The impeller is usually a solid one-piece disc with the vanes formed bilaterally at the periphery. The head-capacity characteristic is similar to the conventional centrifugal pump, since increase in head is accompanied by a decrease in capacity. The power-requirement characteristic of peripheral pumps is the reverse of the centrifugal, as the power falls off with a decrease in head.

Compared with reciprocating and rotary pumps, they are not so positive in displacement, but are sufficiently positive to generate excessive pressures when the discharge line is shut. For this reason, it is not the practice to throttle such pumps at the delivery unless a by-pass back to the suction is provided.

Useful properties are:

(a) ability to self-prime;
(b) tolerance of large proportions of undissolved gases;
(c) high suction lift.

For capacities up to some 40 gpm, peripheral pumps are more efficient than centrifugal pumps and can develop a greater head (around 150 psi) in a single stage. Their use is limited to:

(a) fluids with viscosities below 3 poises;
(b) fluids which are free from gritty solids.

Typical applications are the pumping of hot and volatile fluids. Some designs, suitably modified for the low temperatures encountered, have been used for pumping liquefied gases such as liquid oxygen.

The foregoing, which illustrates the major points of design and performance of the main types of mechanical pump, should prove a useful aid for the preliminary selection of the basic type of pump. In general this will be a

Table I. Operating Characteristics of Pumps

Type of Pump	Flow	Valves	Effect of Increasing Head on CAPACITY	Effect of Increasing Head on POWER	Effect of Decreasing Head on CAPACITY	Effect of Decreasing Head on POWER	Effect of Marginal NPSH on CAPACITY	Effect of Closing Discharge on PRESSURE	Effect of Closing Discharge on POWER	Effect of Entrained Gas on CAPACITY	Recommended Applications and Advantages	Limitations
CENTRIFUGAL	Steady	None	Decreases	Decreases	Increases	Increases	Some reduction	Increases to maximum	Reduces to minimum	Severe-to-total reduction if over 5%-10% 20% with special designs.	Medium heads. Large capacity up to 70% solids.	Not self-priming. Fluids of viscosity greater than 5 poises. Vapour lock. Lowest useful capacity about 20 gpm.
VERTICAL CENTRIFUGAL	"	"	"	"	"	"	"	"	"	"	Low NPSH installations.	
RECIPROCATING	Pulsating	Inlet and Outlet	None	Increases	None	Decreases	Severe reduction	Destructive	Destructive	Small reduction	High pressure. Low capacities. High suction lifts. Self-priming.	Wear on valves and rubbing surfaces. Large size for capacity.
DIAPHRAGM	"	"	"	"	"	"	"	"	"	"	Low capacities, low pressures. High suction lifts. Moderate percentages of solids. Self-priming. Glandless.	Diaphragm material. Wear on valves.
ROTARY (GEAR)	Steady	None	"	"	"	"	"	"	"	Some reduction	High-to-moderate pressures. High suction lifts. Low capacities. Self-priming. Do not agitate liquid.	Close tolerances need lubricating properties in liquid.
SCREW	"	"	"	"	"	"	"	"	"	"	Morneau types tolerate large percentage of solids.	Stator material.
SLIDING VANE	"	"	"	"	"	"	"	"	"	"	Some types will handle slurries.	Close tolerances frequently require liquid to have lubricating properties.
PERIPHERAL	"	"	"	"	"	"	"	"	"	"	Handle large volumes of undissolved gases. Self-priming. Low NPSH values. Moderate. High heads. Low capacities.	Liquids not above 3 poises. Solids. Capacity not above 40 gpm.

centrifugal, unless this type is clearly unsuitable for the work at hand.

There are, however, two other important considerations which affect selection. One is the problem of providing the proper suction conditions and the other is the mechanical problem of making the pump liquid-tight where the character of the fluid so demands. The first problem brings us to the concept of net positive suction head (NPSH), knowledge of which is necessary for determining the best layout at the inlet end of a pump and for specifying the most critical operating condition.

Net Positive Suction Head

The NPSH is the actual head existing at the inlet nozzle of a pump minus the vapour pressure of the liquid being pumped (at the temperature prevailing at the inlet). It is important to distinguish between available and required NPSH. The available NPSH is a property of the piping system in which the pump works, whereas the required NPSH is a function of the design of the pump and is related to the properties of the fluid. It is a measure of the energy necessary to overcome losses in the entrance passage of the pump and to transfer liquid into the impeller vanes without vapour cavity formation upsetting the performance of the pump (See Fig. 6).

Cavitation, as this latter phenomenon is termed, occurs when the pressure of the fluid falls below its vapour pressure, and consists of the formation of bubbles of vapour, and their collapse at a point of higher pressure. This sudden collapsing, which occurs near the periphery of the impeller in the case of a centrifugal pump, can have very damaging mechanical results and can also lead to increased corrosion where the material of construction owes its corrosive resistance to a protective film. Furthermore, a large proportion of vapour formation will reduce the output of the pump and eventually stop it functioning altogether. The pump installation system must therefore be suitably designed to prevent such occurrences and this will be the case if the NPSH provided is in excess of that required by the pump. The problem here is that the pump-maker is seldom the designer of the installation. The solution lies mainly with the engineer, who should provide suitable NPSH conditions at his plant with guidance from the pump-maker.

A prospective pump-user may find himself in a situation where a pump is required for either:

(a) a new plant; or
(b) an existing installation.

In both instances he will have to consider NPSH.

The installation NPSH will be given by the equation

$$NPSH = H_a \pm H_l - H_v - H_f \quad \ldots . (1)$$

where H_a = pressure of the atmosphere at the surface of the liquid being pumped in ft of liquid;
H_l = difference in elevation of liquid surface and centre line of pump;
H_v = vapour pressure of fluid at inlet conditions in ft of fluid; and
H_f = total pipe-line losses including friction, ft of fluid

From the above, the maximum possible suction lift (H_s) in ft of fluid will be given by

$$H_s = H_a - NPSH_p - H_v - H_f \quad \ldots . (2)$$

in which the NPSH value is that required by the pump.

In practice a margin must be allowed between the NPSH values, especially as marginal NPSH provided with a certain kind of pump may lead to uncertainty in operation. The suction lift to be provided in an installation will then be given by.

$$H_s = H_a - (NPSH_p + m) - H_v - H_f \quad \ldots . (3)$$

where m is the safety margin in ft over and above the NPSH required by the pumps. Figs. 9 and 10 show typical centrifugal-pump NPSH characteristics. They also show a useful property of centrifugal pumps: namely, that throttling the discharge to reduce capacity automatically reduces the required NPSH, and therefore gives a higher suction lift. It will be noted that the minimum NPSH with these particular pumps is about 6 ft and the maximum is 42 ft.

The following NPSH values based upon water may be given for different kinds of pump. Those asterisked were obtained by means of Equation (2) from values of practical suction lift given in manufacturers' literature.

(*a*) *Centrifugal Pumps*

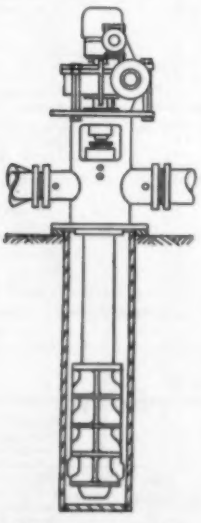
Self-priming pumps	*14—18* ft of water[3]
Normal horizontal pumps	*10—14* ft of water[2]
Slurry pumps	*22—24* ft of slurry[1]

(*b*) *Positive-displacement Pumps*

Reciprocating pumps, including diaphragm pumps	*11—12* ft of water[5]
Rotary pumps	7—12 ft[6]

(*c*) *Peripheral pumps* 5—12* ft[7]

Water-NPSH values are conservative for other fluids such as hydrocarbons. Not a great deal is known about the effect of fluid properties upon NPSH.



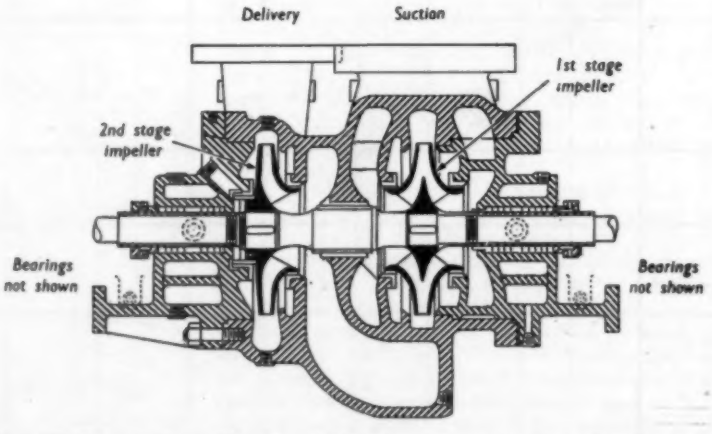


Fig. 11 (left). Vertical pump for low NPSH conditions. Fig. 12. A double-suction, two-stage hrozinotal pump (Hayward Tyler Ltd.).

From Equation (2) it will be seen that an increase in temperature will cause H_v, the vapour pressure, to increase, with the result that the maximum lift (H_s) will diminish. An increase in density will also cause a reduction in suction lift, since in Equation (2) the atmospheric pressure (H_a), expressed as ft of liquid, will decrease with an increase in density. In the case of centrifugal pumps, the statement made earlier regarding the independence of head developed and liquid density holds good provided the NPSH requirement for a given output is met.

There will be situations where the available NPSH is so low as to be below the NPSH required values of normal pumps. Examples are the pumping from evacuated vessels at ground level, or the pumping of volatile liquids at their boiling point: in both these instances, as can readily be seen from Equation (3), the value of the suction lift will be negative, as in the former case H_a will be nearly zero while in the latter case H_v will be almost equal to H_a. This means that a suction head of adequate magnitude must be provided at the pump, whereas the location by definition does not allow this readily. This kind of problem, which frequently occurs in industry, and its possible solution have been discussed by Taylor.[8] Some of the ideas described, such as the use of jet pumps, heat exchangers for subcooling, should be treated with caution, especially where corrosive fluids or fluids containing solids are concerned.

The most practical solutions are to use:

(a) a vertical pump of one or more stages lowered into a pit (Fig. 11);

(b) a horizontal two-stage pump wherein the first stage consists of low-head centrifugal with a double suction (Fig. 12).

The latter (b) is a notable example of the pump-makers' ingenuity. While the entrance losses can be reduced by increasing the cross-section of the pump near the impeller eye, the increased velocity of the impeller at the eye would increase the required NPSH so that the two effects tend to cancel out. The use of the double suction thus reduces the required NPSH at the first stage.

In selecting pumps for such circumstances, it is useful to bear in mind that of all the types available the centrifugal is the one whose capacity is least effected by conditions known as marginal NPSH, which arises when provided and required values are close together. Wherever possible, low NPSH conditions should be avoided by giving the vessels containing liquids plenty of elevation.

Design of Suction Pipe-work

Where the pump is to be located in a new plant the suction piping system is best designed as was indicated earlier by means of Equation (3). The pipeline losses will require estimation by means of expressions for fluid flow, and allowances for bends and constrictions and fittings in the system will have to be made. In the case of centrifugal and other rotative pumps, the value of fluid velocity to be substituted in the friction equation is readily obtained from the capacity and the cross-sectional area of the pipe-work.

With reciprocating pumps, however, the flow at the inlet fluctuates and frictional losses must be estimated for the maximum velocity. This is given by the following expressions of Hefler,[9] in which U.S. gallons have been converted to Imperial gallons.

(1) Ordinary reciprocating pumps

$$V\ max. = \frac{GPM}{1.17\ d^2} \qquad \ldots.(4)$$

(2) Double-acting simplex

$$V\ max. = \frac{GPM}{1.50\ d^2} \qquad \ldots.(5)$$

(3) Double-acting duplex

$$V\ max. = \frac{GPM}{3.44\ d^2} \qquad \ldots.(6)$$

The provision of a surge chamber in the pump suction line enables a reduction of the maximum flow to a value $\frac{1}{\pi}$ of its value.

In the above $V\ max.$ = maximum velocity in ft/sec.;
GPM = gallons per minute;
d = internal diameter of pipe in inches.

Once the type of pump has been selected, various losses may be determined using velocities calculated from one of the above expressions. Once the NPSH required by the pump is known, it will be possible to determine the suction head or suction lift as the case may be.

The main rules to be followed in the design of the suction lines are:

(a) make them as short as possible and keep the number of bends to a minimum; and

(b) provide sufficient bore of pipe consistent with economy, to keep frictional losses to a minimum. The velocities should seldom exceed 5 ft/sec.

(c) The bends in the suction piping should be of the standard long-radius type, whether of the screwed, flanged or welding patterns. Valves should not have restricted areas when fully open and their number should be kept as low as possible. Strainers should also be avoided. If absolutely necessary, they should be large enough to keep the velocity through the strainer element to below 1½-2 ft/sec.

(d) The pipelines should have a gradual slope over their whole length so as to avoid trapping of undissolved gases. Expansion pieces, which are frequently necessary for making the final connection between pump and pipe-work, should be of the eccentric type to avoid pocketing of vapour.

The discharge piping design is less critical than that of the suction line and will not be dealt with at this stage.

Calculation of NPSH for Centrifugal Pumps

An approximate estimate of this entity can be obtained from the head-capacity curve and from the speed of rotation of the particular pump. This is useful when the NPSH is not readily obtainable from other sources.

Addison[10] gives the following simple relation between the head developed and NPSH.

$$NPSH = \sigma H_e \qquad \ldots.(7)$$

In the above σ is a cavitation factor and H_e is the head developed in ft.

For single-entry pumps the cavitation factor varies according to the specific speed as follows:

Specific speed in ft	10	20	50	75	100	115	130	150	170
Cavitation factor	0.12	0.20	0.40	0.62	0.87	1.05	1.20	1.42	1.60

Specific speed is given by

$$N_s = 0.0174\ \frac{RPM \times \sqrt{GPM}}{H_e^{\frac{3}{4}}} \qquad \ldots.(8)$$

The values for capacity and head in this expression are best taken at or near the point in the curve corresponding to maximum efficiency.

To be continued.

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THE MICROMEROGRAPH

A New Instrument for Particle Size Distribution Analysis

By DR. F. S. EADIE* and DR. R. E. PAYNE*

THE Micromerograph was developed to fill a need for a fast accurate method of determining the particle size distribution of powdered materials in the sub-sieve size range. Since the finest standard sieve has aperatures 44 microns on a side, the particle size distribution of powders finer than this must be obtained by other indirect methods. As powders with particles in the sub-sieve range are in common industrial use, many different methods of determining the distribution in size of the particles have been developed. Before the development of still another new method was undertaken, all techniques including microscopic examination, liquid sedimentation, and air elutriation were investigated thoroughly. All were discarded as unsuitable. Some were inherently inaccurate. Others were good only for a limited variety of materials and others took an impractical length of time for a complete analysis.

Sedimentation in still air at atmospheric pressure was chosen as the method to be developed, since it is applicable to a wide variety of powdered materials. Eventually a technique was developed in which a cloud of particles, well separated from one another, is introduced at the top of a sedimentation column. The individual particles all fall the same distance at their terminal velocities on to the pan of a recording balance. Since terminal velocity is a function of the particle size and density (given for spheres by Stokes' Law) a cumulative weight curve plotted against particle diameter can be obtained directly from the recorder chart (see illustration heading article).

Particle size distributions of dry powders with particle size ranges from 1 to 250 microns (depending somewhat on the true density) are obtained easily from the Micromerograph employing the above technique. A partial list of powders analysed includes: iron, tungsten, alumina, gold, zinc oxide, iron oxide, silicon carbide, graphite, activated carbon, lime hydrate, sulphur, limestone, kaolin, penicillin, sulpha-thiazol, aspirin, cocoa, wheat flour, plastic moulding powders, synthetic ion exchange resins, cracking catalyst, diatomaceous earth, and many others.

The particles of powders used in industry range in size from the large particles found in very coarse grinding wheels down to the sub-microscopic particles of carbon black and materials used for paint pigments and polishing rouge. In general, wherever a powder is used industrially there is an optimum particle size distribution suited to that use. Particles too large for a particular application result in an inferior product, while grinding the particles to too small a size is an expensive waste of effort and again may give an inferior product.

Powders may be described, for example, as lumpy, free flowing, smooth, agglomerated, sticky, and so on. All such properties have a dependence on the particle size distribution and particle shape as well as the strength of the particles and the moisture content. From such properties one might make a vague estimate of the average particle size of the powder, and hence get some idea of whether the powder is suitable for a particular application. Since such a description of a powder is hopelessly inadequate for quantitative work, various methods of determining the particle size distributions of powders were developed. One of the best known methods is sieve analysis. The coarser screens, when carefully used, give very satisfactory particle size distribution analyses in the larger size ranges. Very fine screens from 100 mesh to 325 mesh are also very useful for many materials. They are, however, fragile and with some powders cannot be used without wetting the powder to keep it from agglomerating into lumps that will not pass through the holes. Sieves finer than 325 mesh are impractical as the wires become so fine that the size of the hole varies because of movement and breakage of the wires.

* *Sharples Research Division.*

Many methods have been developed for particle size analysis of powders in the sub-sieve size range. Some of these, such as nitrogen adsorption measurements, determine the total surface area of a given mass of powder. From theoretical considerations, these measurements can be reduced to give an estimate of the average particle size for the powder if enough information on particle shape is available; however, many powders with widely varying particle size distributions may have the same *average* particle size and the same *total surface area per unit weight*. Methods which give only a single average size are of limited interest. Since they are seldom adequate for the designation or control of a powdered product, they will not be discussed further in this paper.

Liquid and gas sedimentation and air elutriation methods are based on the principle that a particle moving with respect to a fluid is subjected to frictional forces which are dependent on the particle size. Such forces can be used to separate a group of particles into different size ranges and hence to obtain a particle size distribution for the group. Drastically different in nature is the microscopic counting method which depends on direct measurement of the particle size of a large number of particles to obtain a particle size distribution curve. The Micromerograph has a number of advantages over these methods of analysis and, after discussing some of the problems of particle size technology which confront the foregoing methods of analysis, the nature of these advantages will be considered.

Extended investigations have shown that the proper technique to be used in powder metallurgy and the properties of the finished product depend a great deal on the particle size distribution of the powdered metal. The large surface area of small particles results in a large area of contact between particles. In addition, small particles sinter at lower temperatures than large particles. To obtain the best compacting, high density and high grain strength, a distribution is desirable such that small particles are available to fill the voids between larger ones. The production of a material which has several different properties, for each of which there is an optimum particle size, may require the mixing of several different batches of the same powder, each with a different narrow distribution in size. Control of such a process depends on obtaining accurate data on the particle size distribution of each batch so that the proper proportions of each component can be used.

Problems similar to those in powder metallurgy are encountered in the manufacture of ceramics. An example of the application of the Micromerograph to the solution of these problems is that encountered by a manufacturer of ceramic coatings on metal. A coating having high heat conductivity and good adherence to the metal under severe operating conditions was required. Batches of material had been made which had high heat conductivity and low adhesive strength, low heat conductivity and high adhesive strength, as well as batches poor in both respects and good in both respects. Significant differences could not be recognised between batches before coatings were applied although very careful tests were made before firing test samples. Variations in the particle size distribution of the material was suspected of being an important factor. However, no significant differences in distribution between the various batches could be found using liquid sedimentation, air elutriation, microscopic examination, or air permeability methods.

The solution of this problem was obtained almost accidentally. A Micromerograph had been installed for use on an entirely different process. As a matter of scientific interest, the laboratory analysed this material on the new Micromerograph for comparison with results from the other methods of analysis. The Micromerograph quickly showed that one particular narrow size range of particles had to be present in the material to give good adherence whilst another quite different, but also narrow size, range was necessary to get best heat conductivity. A wide distribution in size including both these particle size ranges was unsuitable since it included too many other particles which did not make an effective contribution. Micromerograph analysis of the successful product showed a very pronounced bi-modal distribution. By combining different lots according to their particle size distributions found on the Micromerograph, the coarse and fine materials were blended to give the proper bi-modal distribution consistently. In reviewing the work previously done on this material using the other methods of distribution analysis, it was found that none gave the necessary definitions and accuracy to pick out the bi-modal character of the particle size distribution which was necessary for a satisfactory product. Thus, even after the solution of the problem was known, the Micromerograph provided the only practical means of control of the process.

Relevance to Air Pollution

Air pollution due to stack effluents is becoming an acute problem in many communities. A solution in many cases

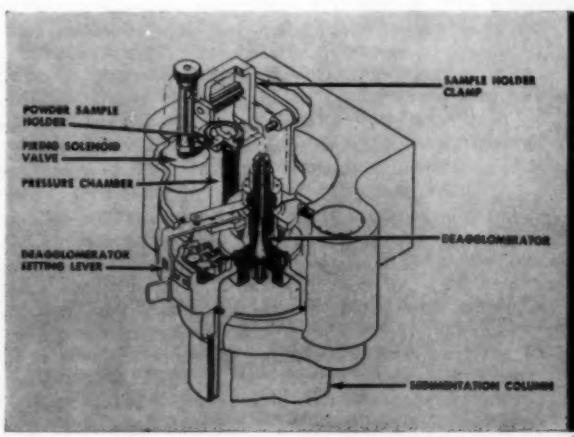


Fig. 2. Section of the Micromenograph powder sample feeder and deagglomerator.

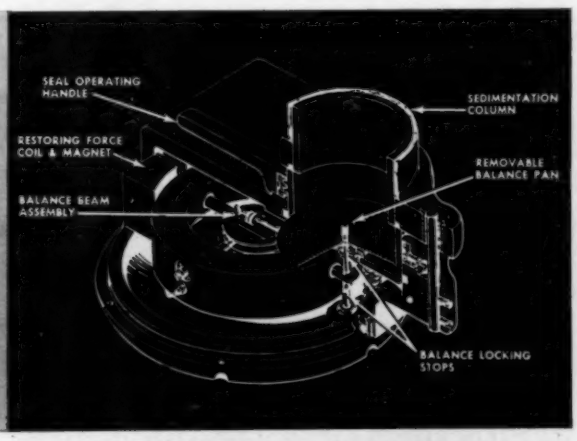


Fig. 3. Section showing the servo-electronic balance, housing and sedimentation column.

is the installation of efficient collectors to remove the fly ash from the effluent. The composition of fly ash is extremely variable, depending on the type of fuel and the burning conditions. In addition, the particles making up the fly ash may be hollow spheres formed from impurities which have been melted while being carried off by flue gases and spherodized by entrapped gas. These particles then have a very low effective density so that they sediment very slowly in air and have a good chance of being dispersed by winds before reaching the ground. In some collectors only those particles with the relatively large physical size but low settling velocity will be collected, whereas smaller more dense particles with a high settling velocity in air will escape. In other collectors, the reverse will be true. Evaluation of such collectors using methods of particle size analysis such as sieve analysis, microscopic examination, or liquid sedimentation are likely to be misleading. In both sieve analysis and microscopic examination, these hollow particles will show up as large particles in the collected material or the effluent. Such analysis, however, gives no information about the air sedimentation properties of the material due to its extremely variable density. Liquid sedimentation suffers in this case from the fact that the particles, because of entrapped air, exhibit widely varying density so that no direct conclusions can be drawn about the settling velocities of the particles in air. The Micromerograph on the other hand is the ideal instrument for evaluation of fly ash collectors, since the settling velocities of the particles in air are measured directly. From the Micromerograph analysis of the powder escaping the collector, direct conclusions can be drawn about the percentage by weight of the fly ash in the effluent which will settle under any given wind conditions within a certain distance from the stack. Cumulative weight curves for several samples of fly ash plotted against settling velocity in still air are shown in Fig. 4, and against particle diameter in Fig. 5.

Close control of particle size is important in the abrasives industry. The coaser grades of abrasives are easily analysed using sieves. Very close control is required for the fine polishing grades. In these the presence of a small percentage by weight of large particles can make it impossible to attain highly polished surfaces. Different grades of such material are sold according to a single particle size specification. Unfortunately, since the sizes are generally in the sub-sieve range, accurate data on the particle size distribution cannot be obtained with screens. Clearly it would be very nice if all the particles in such a powder were the same size: however, this is far from being achieved in practice. As a result, any specification giving only one parameter is inadequate. If the one size stated is the mean size, some knowledge of the size of the largest particles present is required because such particles can make deep scratches on a fine finish. If the size of the largest particle is stated in the specification, the speed of polishing may be unexpectedly slow because of an excessive weight percentage of powder in the smaller size ranges. A highly uniform abrasive material would be invaluable in metal finishing processes.

Particle size distribution curves from Micromerograph analyses of two abrasive powders are shown in Fig. 6. The particle size given by the manufacturer is in the neighbourhood of the median diameter. It is seen, however, that the size of the largest particle present is almost three times the quoted figure. For use in a single process, as long as the same distribution can be obtained consistently, the absolute magnitude of the particle sizes is of little concern. The Micromerograph is an ideal control instrument for checking the quality of such materials, since where absolute particle sizes are not required the recording chart can be interpreted directly, with no calculation other than placing a template over the chart to determine whether or not the pen deflection falls within a certain range.

Development Problems

In developing the air sedimentation method used in the Micromerograph for particle size analysis, one of the first problems encountered was that of dispersing the powder adequately. The method adopted was that of blowing the powder into the sedimentation column through the annular slit between two mating conical surfaces. A fixed volume of dry nitrogen is used to carry the powder from a small sample chamber through the slit. Aerodynamic shear forces in the slit then separate the individual particles so that they settle individually in the sedimentation column. As the adhesive force between particles and the fragility of the particles vary from powder to powder, a wide range of available shear forces for this deagglomerating process was required. This was accomplished by using a variable nitrogen pressure and a variable slit width.

The correct nitrogen pressure and slit width for any powder are determined by making successive analyses at various pressures and slit widths. It is to be expected that particles agglomerated due to adhesive forces will separate under forces smaller than those required to break the particles. Thus, as the nitrogen pressure is raised, cumulative weight curves are obtained which show a shift to the smaller particle sizes as deagglomeration becomes more and more effective. A range of pressures usually can be found at which the particles are all deagglomerated and none broken. Changing the pressure through this range does not result in a shift of the distribution curves. Increasing the pressure beyond this range may sometimes cause breakage of particles. This will be again shown by a shift of the distribution curves to the smaller particle sizes. What is happening in any particular case can be determined by microscopic examination of the powder which has passed through the deagglomerator, and inference from examination of the curves. In the case of insufficient deagglomeration, the numerous small particles appear as agglomerates. Particle breakage can be detected by a change in the characteristic particle size and shape.

The particles coming from the deagglomerating slit form a cloud in the top of the sedimentation column. This is a vertical tube sealed at both ends with the pan of the recording balance at the bottom. The length of the tube is 7 ft. 4 in. and its inside diameter is 4 in. The sedimentation column is normally filled with air at atmospheric pressure. The nitrogen carrying the powder raises the pressure inside the column slightly above atmospheric pressure, but this has no measurable effect on the sedimentation. For use with powders reacting with oxygen, the sedimentation column can easily be filled with any other gas desired.

Slight corrections to Stokes' Law to take into account the initial gas and particle velocities at the deagglomerator slit are incorporated into templates used for interpreting the recorder chart.

The rate at which properly dispersed particles sediment in a gas is determined by their density, geometrical size, and shape. Particle size when determined by a single parameter is, of course, a rather arbitrary term except when the shape of the particle is a sphere. Particle size as measured in the Micromerograph refers to the diameter of a sphere which would fall the same distance in the same time as any given particle. As particles of the same size and shape falling in different orientations have different terminal velocities, the effect of shape tends to be averaged to give a particle size which lies between the extreme dimensions of the particles.

Stokes' Law applied to a small spherical particle sedimenting in a gas under gravity gives the following equation relating the time of fall, the diameter of the particle, its density, and the settling distance. The density of the gas is assumed to be small compared to that of the particle.

$$D^2\rho = \frac{18\mu S}{g\ t} \qquad \ldots\ (1)$$

where D is the particle diameter,
ρ is the particle density,
μ is the viscosity of the gas,
S is the settling distance,
t is the settling time, and
g is the acceleration of gravity.

The settling distance S is the same for all particles. Hence, Equation 1 can be simplified for particles of constant density to

$$D = \frac{K}{\sqrt{t}} \qquad \ldots\ (2)$$

where K is a constant.

The settling time t of the particles is measured from the time the powder is released into the top of the sedimentation column. The initial shock wave (which is caused by the gas entering the column) hits the pan of the recording balance and the resulting sudden deflection and return of the recorder pen provides a convenient index on the recorder chart from which to measure the settling time. When the particles reach the pan of the recording balance their weight is recorded on a chart moving at a suitable velocity. For each settling time t there corresponds a value of D given by Equation 2. Thus, after any time t from the start of a run, the accumulated weight of powder on the balance pan is known to be due to particles of diameter greater than the value of D corresponding to the settling time t.

An automatic servo-controlled torsion balance is used in the Micromerograph to record the weight of sedimented powder. Any deflection of the balance beam due to a weight on the pan is detected by means of a balanced differential transformer. The signal coming from the transformer is amplified and demodulated, causing a direct current proportional to the signal to pass through a coil mounted on the balance beam and situated between a pair of permanent magnets. The resulting force on the coil compensates for the weight on the pan so that the balance beam never deviates more than a few thousandths of an inch from its balanced position. The current through the restoring force coil necessary to balance the weight on the pan is used to actuate the recorder pen. This current is always proportional to the weight on the balance pan so that a continuous record of the weight is obtained.

The balance is extremely rugged so that untrained personnel are not likely to damage it by rough usage. In the Micromerograph, the balance is supplied with two sensitivities. These give full scale deflections of approximately 25 mg, and 50 mg, on the recorder chart. The recorder chart may be read to $\pm\ \frac{1}{2}\%$ of full scale.

Comparison With Other Techniques

Micromerograph analyses of particle size distributions in the size range above 100 microns can be compared directly with sieve analyses. Comparisons in the sub-sieve size range are more difficult to make because of the lack of agreement between other methods of analysis. By making powders with all particles nearly the same size and spherical for ease of measurement, comparisons with microscopic techniques are possible. Such comparisons indicate the same probable error of $\pm 3\%$ in this size range.

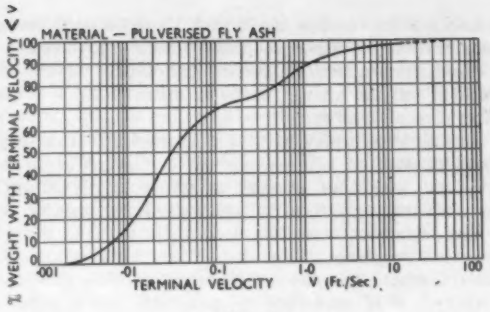


Fig. 4

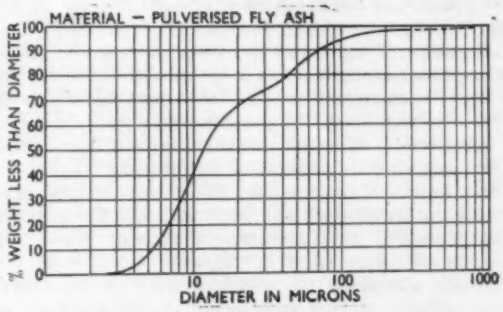


Fig. 5

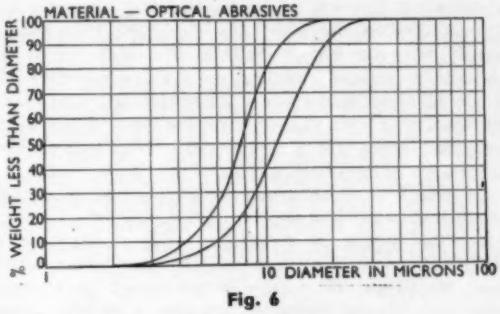


Fig. 6

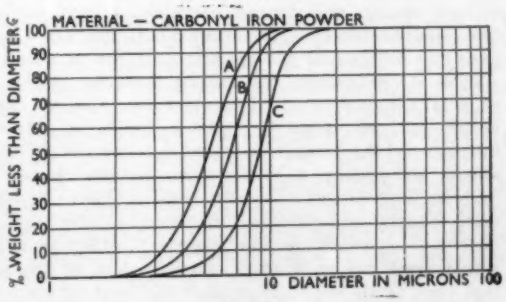


Fig. 7

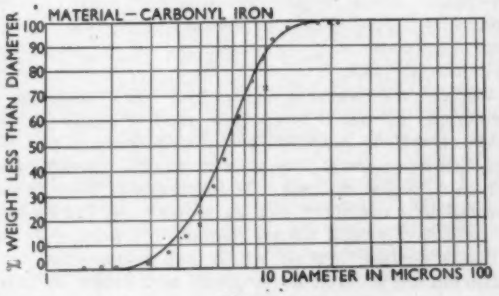


Fig. 8

Using a microscope the linear dimensions of the individual particles of a powder can be measured directly. This method has certain inherent difficulties which can be avoided only if all the particles measured are nearly the same size and spherical.

The first difficulty is that of sampling. If a thousand particles with an average size of 10 microns are measured the total weight of powder examined is of the order of one-half microgram or 10^{-9} pounds. If the sample is from a one pound lot it is always doubtful whether those 1,000 particles weighing 10^{-9} pounds were representative in size for the whole lot. After a representative sample has been obtained it is necessary to distribute the powder on a slide in such a way that every area of the slide has a representative distribution of particles on it. Most methods of spreading the powder will result in some separation of the small and large particles. In measuring the particles, therefore, a large enough area of the slide must be examined so that any local variations in the particle population are evened out.

Associated with the microscopic technique is the fact that only two dimensions of any particle are ever seen at one time. Determination of a third dimension is a laborious process when a large number of particles are to be measured and is rarely attempted. Many different techniques have been developed for obtaining a mean particle diameter from a measurement of two dimensions. All depend on the orientation of the particles on the microscope slide being random. The correctness of this assumption depends again on the way the particles are spread out on the slide. Having made this assumption there are a number of methods of associating with each particle a number denoting its size. Some methods are more accurate or quicker than others, but all suffer from the fact that one cannot give the size of an object of irregular shape by a single parameter when only two dimensions can be measured.

It is difficult to determine by microscopic measurements the weight distribution as a function of particle size. Since the weight of a particle varies as the cube of its diameter, a few large particles can contribute a large fraction by weight of a powder compared to many small particles. As an example, consider a powder consisting of one million one micron particles to each particle of one hundred micron size and no other sizes. On a number basis the differential particle size distribution would show a peak at one micron, one million times the height of the peak at 100 microns. On a weight basis, however, the peak at 100 microns would be equal in height to that at one micron. If the powder is examined microscopically, the chance of finding a 100 micron particle is one in a million. This would not be a serious matter if powders were bought and sold on the basis of the number of particles in a certain size range. Unfortunately, such transactions are on a weight basis so that if this powder was sold, according to specifications based on microscopic examination, as consisting of one micron particles only, a buyer whose application required only one micron particles would have a powder which was only 50% efficient, since 50% by weight of the powder is in 100 micron particles.

Before the Micromerograph was developed, the errors inherent in the microscopic method were laboratory investigated by making a particle size analysis of a powder consisting of irregularly shaped particles extending in size from 1 to 100 microns. In four months, four laboratory technicians measured two dimensions on 70,000 particles. Cumulative weight curves obtained by taking data for two 35,000 particle groups which had supposedly the same distribution differed by as much as a factor of two from each other. In addition to the errors expected from sampling, spreading the powder on the slide and statistical errors, it was found that personal errors of the four technicians were also important. As microscopic counting is very tedious, consistent errors of this type are inevitable after long periods of counting.

As compared to microscopic counting, the Micromerograph enjoys many advantages. The sample used varies between 50 and 100 mg. which is a reasonable size to obtain by good sampling techniques. The single parameter measured is the diameter of a sphere which has the same terminal velocity as the particle in question. In this respect it is important to note that for a particle whose greatest dimension is less than twice the smallest dimension, the equivalent Stokes' diameter does not vary by more than 10% from that of a sphere of equal volume. The many millions of particles present in a sample of powder of the size used for Micromerograph analysis give good statistical accuracy. In addition, the results are obtained almost automatically so as to be independent of the operator. The results, of course, are more accurate and are obtained in a much shorter time, i.e. in, at most, a few hours as compared to days or weeks for microscopic counting.

One method of particle size distribution analysis in use in many laboratories is that of liquid sedimentation. There are many variations on this method all employing the same principle, but differing in the method of determining the amount of sedimented material. The method consists of dispersing powder in a column of liquid and measuring the rate at which the powder settles out. The rate of settling may be determined by withdrawing samples for analysis, turbidity measurements, direct weight or volume measurements, differential manometer measurements, or by density measurements.

Each of the liquid sedimentation techniques has problems which are peculiar to it, but all of them have several problems in common. The first of these is that of dispersing the powder in the liquid medium. In most cases, a dispersing agent is required to ensure that all particles are separated from each other. Since there is no general technique for finding a good dispersing agent it is usually a matter of cut and try when making an analysis on a new powder. This problem itself may require several weeks of work. The use of such dispersing agents may cause additional difficulties. Many disperse the powder by depositing electrical charges on the individual particles so that they repel one another. As the particles sediment towards the bottom of the fluid, the concentration of these charges results in an electric field. This field repels the particles still sedimenting and may result in some never settling out at all. This fact alone could account for many of the divergent results obtained from liquid sedimentation analyses from different laboratories where different dispersing agents are used. One of the well known characteristics of particle size distributions obtained by liquid sedimentation methods is the apparently large percentage by weight of particles which are so small that they do not settle at all.

In most liquid sedimentation techniques in general use the powder to be analysed is dispersed throughout the liquid medium. Hence, the particles start sedimenting at their terminal velocities from all positions in the liquid. A curve showing the accumulation of powder on the bottom of the sedimentation vessel as a function of time is obtained from the experimental data. To obtain a cumulative weight curve, this experimental curve must be differentiated. This procedure results in a loss of accuracy of one order of magnitude, besides being tedious and requiring highly trained technicians.

Another troublesome point associated with dispersing the powder in the liquid medium is that of choosing a zero of time. Since dispersing the powder in the medium

usually involves stirring or shaking at the start of the sedimentation the liquid is still moving in the vessel. This motion persists for a time which is difficult to estimate and interferes with the sedimentation. The time cannot be measured from the moment when all motion ceases since a measurable amount of sedimentation has taken place before this time. On the other hand, it cannot be measured from the moment mixing was stopped since some motion occurs after this time. This effect gives an error at the heavy end of the distribution which is difficult to estimate. In addition, currents developed by the fluid flow, caused by the displacement of liquid by heavy particles, may result in a situation where all the particles sediment down the sides of the vessel while the displaced fluid flows up the centre.

Other types of liquid "updraft channels" are also found to occur. This type of flow is apt to be encountered where the powder represents a significant proportion by weight of the sedimentation system. Stokes' Law can only be applied for particles well separated from one another and does not take into account the effects of such flow on the motion of the particles. Another result of this effect is that small particles fall in the wake of large particles. This is particularly insidious and can be eliminated only by removing all the large particles which sediment quickly or by using an amount of powder small enough so that the particles are well separated in the medium. Convection currents due to temperature variations in the medium are also difficult to eliminate from liquid sedimentation systems.

Advantages of Air Sedimentation

There are many methods of measuring the amount of material settling out of a liquid as a function of time. Most of these have as their major fault the fact that the sedimentation is disturbed by the measurement, with the result that particles take a longer time to settle out than they otherwise would. This problem is avoided in the Micromerograph by measuring the cumulative weight with the servo-mechanical balance whose motions are at the most a few thousandths of an inch. By using air sedimentation for the Micromerograph the other difficulties associated with liquid sedimentation are either avoided entirely or greatly reduced in magnitude. The dispersion and deagglomeration is carried out on dried powder under highly reproducible conditions. All particles settle from effectively the same height so that calculations become simple.

Since the Micromerograph system is pressure-tight, turbulence associated with blowing the powder into the sedimentation column dies away practically instantaneously and effects only the initial velocities of the particles. A correction for this effect is incorporated into the template used for interpreting the recorder chart. Convection currents due to temperature variations have not been a problem. The sedimentation column is made from an aluminium tube and good heat conduction keeps the temperature along the length reasonably constant. In addition, an insulating blanket over the tube prevents any sudden changes in temperature. The dimensions of the sedimentation column have been made large enough for the sample size used in an analysis (0.1 gm.) so that the maximum correction to Stokes' Law to take into account the interference which occurs in multiple particle sedimentation is below 1%. Since the difference in density between air and solid particles is large, no corrections have to be made for variation in density of the medium in the Micromerograph. This leads to a greatly simplified calculation of particle size from the time of sedimentation.

Air elutriation is a method of particle size distribution analysis widely used industrially for powders in the sub-sieve size ranges. The physical principles on which this method is based are the same as those employed in the Micromerograph; however, it is not possible to control air velocity, turbulence, and secondary flow to compete favourably with settling in still air. The Micromerograph requires much less time for complete analyses. In addition, it gives detailed information on the particle size distribution curve while only a few poorly defined points on the curve can be obtained by air elutriation. Since for many industrial applications different narrow size ranges of powders have to be mixed to give a certain over-all distribution, a detailed particle size distribution curve is necessary on the powder in each size range. Close control of the material used in such a process is practical when one uses the Micromerograph, since the percentage of powder required from each size range to give the final desired distribution can be easily calculated. In many cases this allows the use of powders with wider limits on the particle size range, since the correct proportions of each powder can always be calculated. Deagglomeration is perhaps the worst feature of air elutriation as compared to the Micromerograph. Deagglomeration is not reproducible and there may be some grinding. In addition, there is no way to tell whether or not deagglomeration is complete.

The Micromerograph is capable of analysing the particle size distribution of each of the size fractions obtained by air elutriation. Fig. 7 shows the results of Micromerograph analyses of three such fractions of carbonyl iron powder. Curve A shows the distribution in size of the fraction nominally from 0 to 5 microns, Curve B that nominally from 5 to 10 microns, Curve C that nominally greater than 10 microns. In Fig. 8 the solid line indicates the particle size distribution curve obtained by Micromerograph analyses of the feed powder divided by air elutriation into the three size fractions whose particle size distributions are shown in Fig. 7. The circled points show the result of reconstructing the feed curve by adding together the three size distributions shown in Fig. 7 in the proportion indicated by the original elutriation. The crosses indicate the meagerness of the total amount of information on the particle size distribution of this original feed powder which was available from the air elutriation analysis. From consideration of the distribution curves of the three different size fractions, it can be seen that the apparent fairly good agreement between the two methods of analysis is fortuitous.

The time required for a complete Micromerograph particle size distribution analysis on any powder varies inversely as the square of the particle diameter and the density as can be seen from Equation 1. For powdered iron with a density of 7.8 gm./cc, the time for an analysis down to 1 micron is 2¼ hours. Down to 3 microns, however, takes only 20 minutes.

The sample preparation and cleaning time between analyses on the Micromerograph is about ten minutes. This time is ample for removal of the powder from the previous run and insertion of a new sample. No weighing is required since an operator soon becomes proficient in judging the correct amount of powder to use to obtain a reasonable deflection of the recorder pen. Calculation of the complete distribution curve takes between 5 and 10 minutes. This operation can be done concurrently with running another analysis on the instrument. A single operator can run three Micromerographs at the same time with ease, provided the instrument analysis time is over an hour.

THE DEVELOPMENT OF BRITAIN'S PETROCHEMICAL INDUSTRY

by S. A. GREGORY, B.Sc., M.I.Chem.E.

BY the end of 1956 the production capacity for raw materials for the manufacture of aliphatic products from petroleum will be substantially double that set in operation in 1951. Further plans are being laid for the future and it will be of considerable interest to discover then whether the predicted rate of expansion is confirmed. In any case the availability of petroleum raw materials is changing rapidly the shape and details of the chemical industry of Great Britain.

Probably the earliest step towards the production of an organic chemical by synthesis from an olefin on the industrial scale was the work carried out at Skinningrove Ironworks in which ethylene was removed from coke-oven gas by scrubbing with sulphuric acid. This work was echoed during the war when British Oxygen Co. Ltd. installed a gas separation plant at Corby for the purpose of separating ethylene from coke-oven gas to make synthetic ethanol, using sulphuric acid to react with the separated ethylene. After the attempt to use coke-oven gas at Corby there appears to have been no further substantial developments in this field and efforts have been devoted to the utilisation of imported petroleum raw materials or products from them.

Symbolical picture of chemical production are the Horton spheres for storing refinery gases under pressure.

Synthetic Detergents

The first notable plant in the petrochemical field in Britain came into production in 1942. This was the Shell "Teepol" unit at Stanlow which initially operated to deliver 12,000 tons per year. Its raw material was slack wax. After cracking this thermally to produce a suitable range of hydrocarbons they were sulphonated to yield a secondary alkyl sulphate. Similar materials were later produced by Scottish Oils Ltd.

This venture into the field of detergents set the pace for later rapid developments. However, the subsequent steps required the wider development of raw material supply.

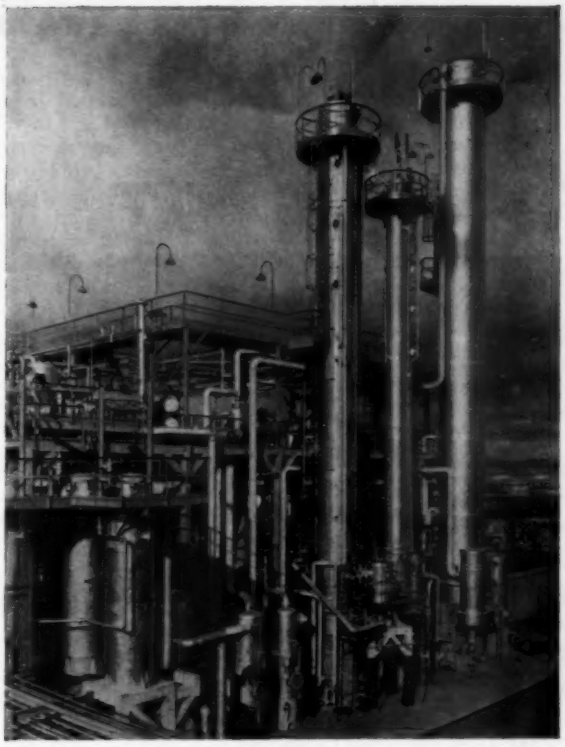
The pyrolysis of petroleum hydrocarbons produces a certain amount of olefins, such as ethylene, propylene, butylenes, etc. This effect is obtained in the older thermal cracking plant and in the newer catalytic cracking plant. Thus olefins appear alongside the upgraded gasoline derived from the cracking operation. Similarly, in the more familiar coke-ovens and gas retorts which operate at higher temperatures than in the normal cracking of petroleum, there are formed olefins, but aromatics also appear.

Much of the early work in the U.S.A. on the manufacture of chemicals from olefins used propylene and butylenes from refinery gases. The picture of the chemical industry thus based was therefore influenced by the olefins readily available. The rise in importance of elthylene as raw material for chemical production led to the development of specific cracking methods designed to produce olefins rather than to upgrade material to gasoline.

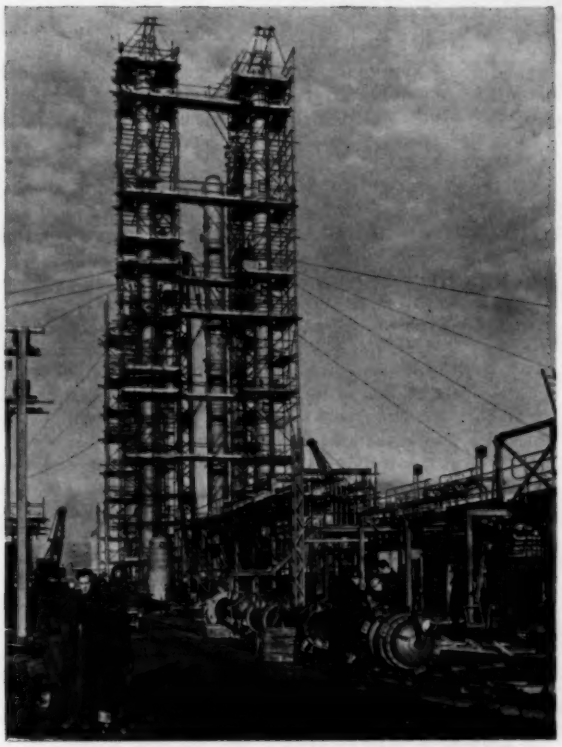
In Germany much work was done on the utilisation of acetylene produced from carbide. Later, this led to the development of methods of making acetylene by special pyrolysis of methane. Currently the Americans are using these methods to obtain acetylene from refinery gas or natural gas. In Britain acetylene is still only made from carbide, either home-produced or imported from Norway.

Changes in the Solvent Industry

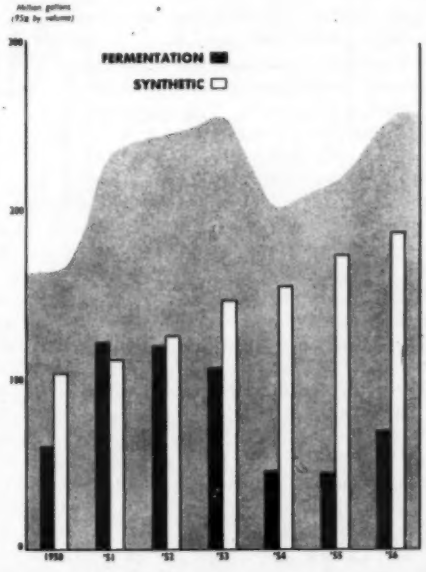
The first British installation for specific cracking was made by British Celanese Ltd. at Spondon. This was put up during the war and even today few details are known about it. At the beginning of the war British Celanese produced about half of the country's cellulose acetate for rayon manufacture. They were therefore the largest consumers of acetic acid, used directly in the process, and of acetone, used in the spinning operation. At that time home-produced acetic acid was made from ethyl alcohol based acetaldehyde, the British industry absorbing some 10,000 tons per year of acid. The Spondon plant solved readily a supply problem, since the ethylene provided



British Hydrocarbon Chemical ethanol plant at Grangemouth.



I.C.I.'s butadiene plant when under construction. This plant is now in operation at Wilton.



Pattern of U.S. alchahol production, 1950-1956. *British figures show the same trend.*

synthetic ethanol, whilst the propylene made it possible to obtain isopropanol from which acetone was readily made by dehydrogenation over a catalyst.

Although the Spondon plant made a contribution to acetone production, by the end of the war it was necessary to import nearly 20,000 tons per year of acetone. This was produced from propylene in the U.S.A. It was logical, therefore, to consider replacing this import by local production. By 1949 two petroleum-based acetone plants were set up to supply the open market. One was established by Shell at Stanlow, initially using a thermal cracker to supply propylene, although changing to refinery gas when the large catalytic cracker was installed in 1952. The other was established at the Partington plant of Petrochemicals Ltd. The Stanlow factory produced isopropanol, acetone, secondary butanol, and methyl ethyl ketone by dehydrogenation of the butanol. The output of the Stanlow plant was about 15,000 tons per year of acetone, whereas the Partington plant had about half this capacity. By this period the prospect of further acetone supplies brought about a change in the method of making acetic anhydride. Immediately after the war the favoured method was to crack acetic acid to yield acetic anhydride. Plans were laid for the installation of a number of plants to use this method. But the cracking of acetone yields ketene from which acetic anhydride may readily be obtained. This increased the prospects for acetone.

In 1951 the Grangemouth plant of British Hydrocarbon Chemicals commenced operation. This was based on specific cracking to yield ethylene and propylene. The ethylene was converted to ethanol which was taken by Distillers Co. Ltd. (half owners of the B.H.C. plant) and used to replace some 30,000 tons previously made by the fermentation route. At the same time capacity for the production of about 22,000 tons per year of isopropanol was installed. The isopropanol was shipped by D.C.L. to the Hull plant of British Industrial Solvents Ltd. to be converted to acetone. This replaced the acetone formerly made at Hull by treatment of ethanol with steam over a catalyst, a process worked at the rate of about 5000 tons per year. I.C.I. at Wilton set going in 1951 a similar plant for the production of acetone derived from propylene made in their own specific cracking unit. This acetone was used inside I.C.I. for the manufacture of methyl methacrylate.

The Partington Plant

The first major plant set up in Britain to crack a petroleum fraction specifically for the manufacture of chemicals was the installation of Petrochemicals Ltd. This used the "Catarole" cracking process, a fixed bed system developed to yield not only olefins but also aromatics. The throughput rate was designed for 75,000 tons per year of naphtha, divided among five furnaces. This yielded some 35,000 tons of aromatic hydrocarbons and about 10,000 tons of ethylene and 7500 tons of propylene. The aromatics were separated from the furnace output by simple condensation, the olefins were separated by low-temperature condensation, and the residual gas was sold to the neighbouring gas-works. The ethylene was converted to ethylene glycol an oxide by the chlorhydrin route. Propylene was processed in the conventional manner to isopropanol and acetone.

This undertaking passed through a period of financial difficulty and eventually was purchased for £5 million by the Shell organisation. With the expansion of chemical sales, the availability of capital, and the existence of new processes, the Partington plant is spreading again. Already the ethylene oxide has been used to provide a raw material for the making of the "Catarex" range of non-ionic detergents. The same material has been used in the ethanolamine plant started early in 1956. Construction is under way for units for the manufacture of glycol ethers, polyglycols, and further non-ionic surface active agents.

By mid-1958 it is hoped that there will be new facilities for the production of 25,000 tons per year of ethylene oxide using the new Shell direct oxidation process. On the completion of this equipment the existing plant will be converted to the manufacture of propylene oxide which will thus greatly expand the existing production.

It has not yet been clearly stated where the extra ethylene and propylene will come from. Will this be a vindication of the "Catarole" process?

Other products envisaged include polyethylene and styrene monomer. In the original project at Partington there were plans for internally produced styrene. A styrene polymerisation unit has been operating for a considerable time using imported monomer, but the availability of ethylene and benzene internally, and the increased demand for styrene for synthetic rubber production, make this expansion logical.

The sole U.K. rights to the Ziegler low-pressure process for polythylene were acquired by Petrochemicals in 1954 and investigation has been made on the pilot scale. Operation on the 1000 tons per year scale is now in train.

The Stanlow Story

The thermal cracking unit which was taken out of commission in 1952 was put back to work in 1953 to supply ethylene to the new factory of Associated Ethyl Co. Ltd. at Ellesmere Port, for the manufacture of ethyl chloride, the main intermediate for the production of lead tetraethyl, and for the manufacture of ethylene dibromide.

The further elaboration of propylene at Stanlow has continued. In the U.S.A. they have developed their synthetic glycerol processes and their epoxy resins. A plant for the manufacture of "Epikote" was set in operation at Stanlow in 1955. Today Stanlow produces about 100,000 tons per year of chemicals, including sulphur. This figure, however, does not include the tonnage of xylene from the platformer which goes to the Wilton Works of I.C.I. for para xylene separation.

The largest installations in the country have been based on specific cracking. In each case these plants have been brought into operation with an assurance that their outputs would be absorbed by the captive markets of their promoters.

The Grangemouth Installation

The Grangemouth plant of British Hydrocarbon Chemicals Ltd. arose from the undertaking owned in equal parts by British Petroleum Ltd, and by Distillers Co. Ltd. It was erected alongside the petroleum processing plant of the firm now called B.P. Refinery (Grangemouth) Ltd. The cracking plant was designed to handle 150,000 tons per year of light petroleum distillate, yielding ethylene and propylene. From the ethanol produced, D.C.L. were able to replace the fermentation alcohol previously obtained from their distilleries at Glasgow and Liverpool, thereby reducing their active distilleries for the production of industrial alcohol to four. The isopropanol was also absorbed by D.C.L.

A further step at the Grangemouth site was the construction of the styrene monomer plant for Forth Chemicals Ltd., an enterprise controlled two-thirds by B.H.C. and one-third by Monsanto Chemicals Ltd. This commenced operation in 1953 with an output of 10,000 tons per year, which supplied half the U.K. requirement and, in particular, the "Lustrex" polystyrene plant at Monsanto's Newport works.

In 1956 Grange Chemicals Ltd. (a joint undertaking owned two-third by B.H.C. and one-third by the Oronite Chemical Co., a subsidiary of Standard Oil Co. of California), set in production a plant for the manufacture of 10,000 tons per year of dodecyl benzene detergent alkylate. This plant polymerises propylene to the tetramer with a phosphoric acid catalyst, the tetramer is alkylated with benzene and then sulphonated.

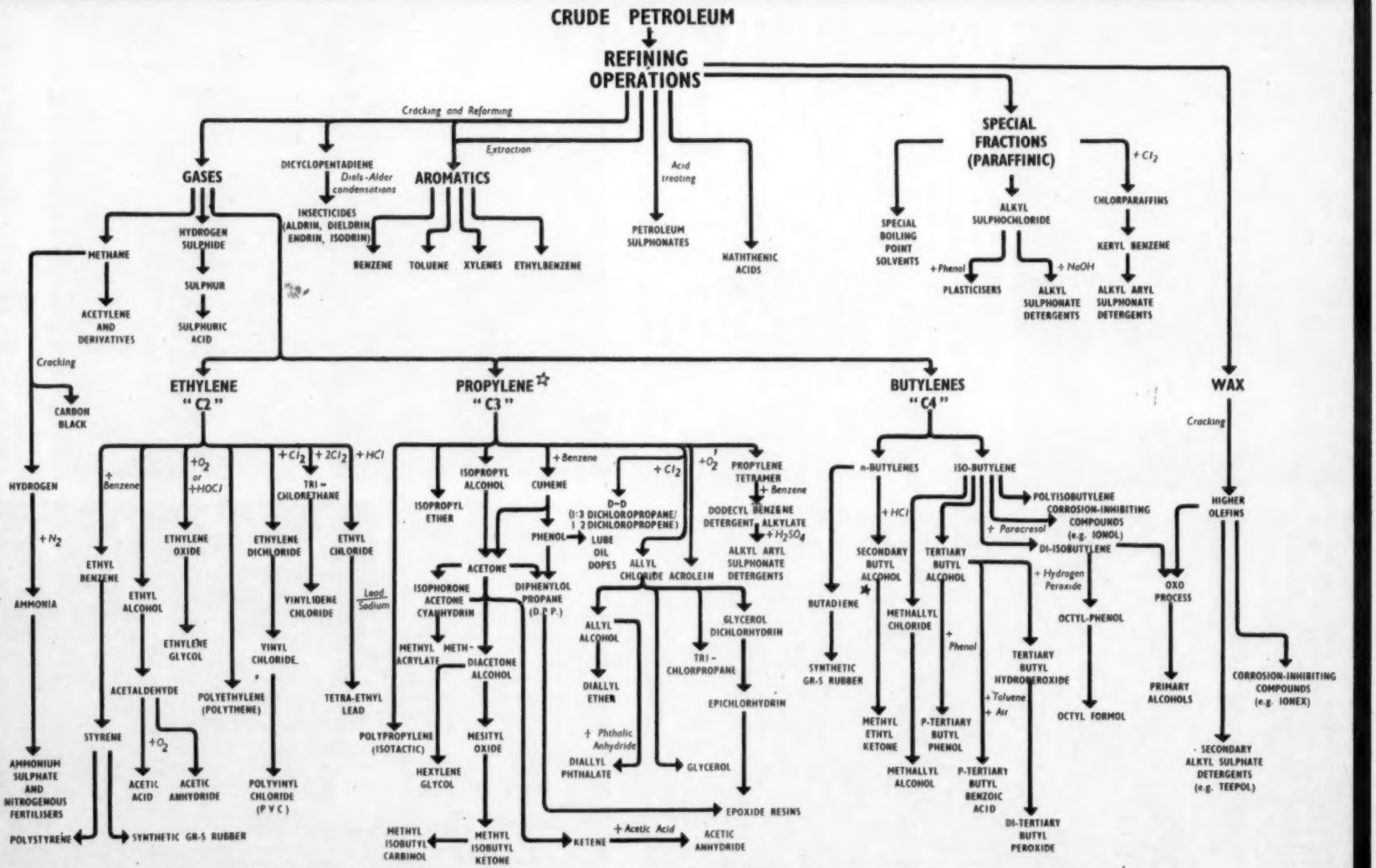
At present there is under construction a plant for the manufacture of polyethylene. This is owned by Gemec Ltd., a subsidiary of Union Carbide Ltd., and it will take ethylene from B.H.C. The throughput of the plant has not yet been published.

Grangemouth is currently producing chemicals at the rate of about 70,000 tons per year. Further major expansions of the original products are to be expected in 1956-7. Fundamental to this expanded output is the addition of further cracking capacity. The programme, to cost £8 million, allows for a cracking plant of 220,000 to 250,000 tons per year throughput. The production of synthetic ethanol is to be doubled. This suggests that D.C.L. envisage the closing down of further fermentation alcohol capacity in the near future. Under this new production scheme it appears that about two-thirds of Britain's industrial alcohol will be synthetic.

Forth Chemicals Ltd. have two further styrene monomer units under construction and it is believed that altogther their plants will permit the production of at least 25,000 tons per year. This is greater than the country's present requirement for the manufacture of polystyrene, the output of which remains relatively steady around 21,000 tons per year. Presumably there is the possibility of export, but above all the new British synthetic rubber industry will be the principal market for the extra material.

The Wilton Installation

During the years after the establishment of the hydropetrol plant at Billingham, investigations were made on the use of certain of the olefins and other materials in the gases. But fundamental to the I.C.I. expansion at the vast new site at Wilton was the strong belief in a future for polyethylene and "Terylene". In particular the development of polyethylene needed large quantities of ethylene. Study showed that the cheapest source would be specific cracking of light oil. By 1951 a cracking plant was installed at Wilton capable of handling 250,000 tons per year. This had a capacity for about 40,000 tons per year of ethylene and 30,000 tons per year of propylene.



FAMILY TREE OF PETROCHEMICALS. Space does not allow comprehensiveness in this chart; in particular two aspects of developments need amplification☆. Production of hydrogen peroxide from petroleum opens up new line of petrochemical synthesis. Shell in the U.S.A. are to produce hydrogen peroxide and acrolein, starting from petroleum-based isopropyl alcohol; this route leads to glycerol, but many other petrochemicals could be made when hydrogen peroxide becomes available. ★GR-S rubber is only one of the butadiene-styrene polymers that are of interest. Other monomers that can be condensed with butadiene include methyl methacrylate and acrylonitrile; I.C.I. will be producing copolymers of both (called "Butakon" copolymers) using butadiene supplied by the Wilton oil crackers.

The ethylene was fed, in part to the ethylene oxide plant (chlorhydrin process) which provided essential raw material for the manufacture of the "Lissapol N" detergent of the non-ionic class, and for the manufacture of "Terylene", and it was also fed to the polyethylene facilities.

The initial capacity for polyethylene was about 15,000 tons per year but two further units were installed raising the capacity to some 45,000 tons per year, when the third unit was completed in 1955. In order to sustain the vast appetite of these units it was necessary during 1955 to buy ethanol for conversion to ethylene. This situation will be relieved later in 1956 when the second 250,000 tons per year oil cracker is commissioned. For 1959, the polyethylene production plan has been set at 90,000 tons per year and a further new cracking unit to provide ethylene is scheduled to be ready by early 1959. It is believed that this unit will handle some 375,000 tons per year of light oil and will yield about 60,000 tons of ethylene.

At present propylene from the first cracking unit is piped across to Billingham for conversion to acetone which is then used for the I.C.I. manufacture of methyl methacrylate. No statement has been made regarding the use of the increased quantities of propylene which will be available but it is fair to guess that at least part will be devoted to the manufacture of polypropylene. Since the advent of the first cracking unit at Wilton the residual gases, hydrogen and methane, have been piped over to Billingham for use in the ammonia synthesis facilities. The recovery of C4 hydrocarbons has been pursued and now the construction of a butadiene plant is proceeding. Butadiene will be used in a copolymer unit expected to be ready in 1956.

After the development of the secondary alkyl sulphate production, the important group of alkylated aromatic sulphonates was introduced. A substantial works for the manufacture of "Santomerse" was set in operation by Monsanto Chemicals Ltd., at Newport in 1949. Shell Chemical Co. also contributed to this output. At this period about 10% of Britain's detergent output was based on synthetic material and amounted to some 50,000 tons per year.

I.C.I. added their "Lissapol N" plant at Wilton to this production in 1950. This material was made by the condensation of ethylene oxide with a suitable phenol. A similar product was introduced by Petrochemicals Ltd.

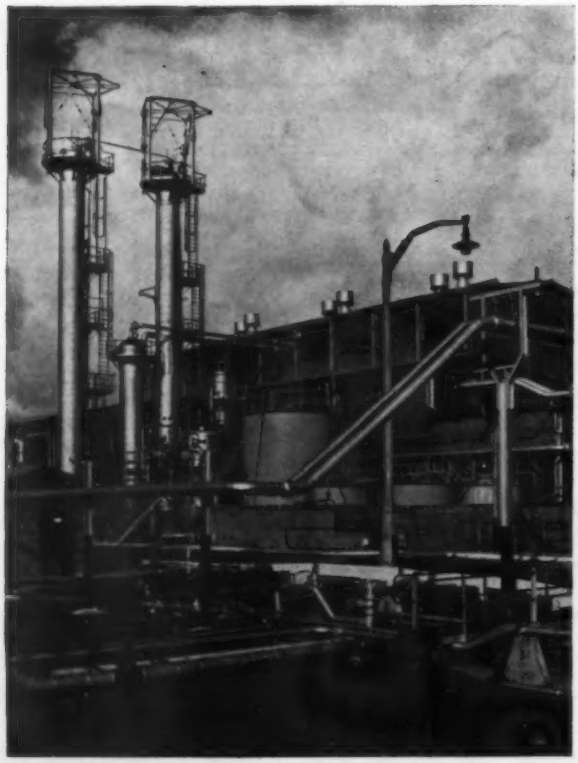
The detergent industry has continued its expansion on the synthetic side, so that by 1955 some 250,000 tons per year were made and at least 50,000 tons exported. The internal consumption of synthetic material accounted for almost 40% of all detergents used. Already in the U.S.A. the proportion of synthetic material used has reached 60% so there are still possibilities for expansion in Britain.

The principal new introduction in this field is dodecyl benzene sulphonate. This is a useful outlet for propylene which is polymerised to the tetramer in the course of manufacture. One plant has been built by Grange Chemicals for its production, and another has been installed by Shell at Shell Haven.

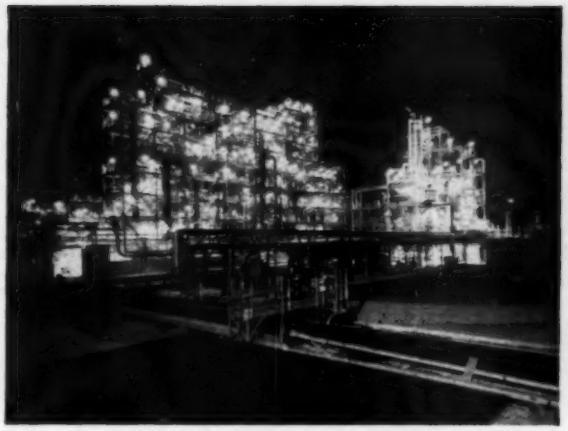
New Departures

In conjunction with their programme for using refinery gas Shell, in association with Fisons, are to build a factory at Shell Haven at a cost of £6½ million to produce 75,000 tons per year of ammonia, and ammonium nitrate-limestone fertilisers using 15,000 tons of ammonia. It is to be presumed that the hydrogen production scheme will be associated with the project to provide North Thames Gas Board with 25 million therms of gas a year, delivered from Shell Haven to Romford under a pressure of 120 psig.

I.C.I.'s programme includes the Billingham project for making a similar amount of ammonia, the hydrogen for which will be prepared from heavy oil by the Texaco partial-oxidation process.



Left. The "Teepol" unit with extraction towers at Stanlow. Above. I.C.I.'s glycol plant at Wilton.



The I.C.I. olefin plant at Wilton.

On the strictly petrochemical front, the principal new departure is the provision of raw materials for the manufacture of synthetic rubbers. British Hydrocarbon Chemicals have almost completed a plant for the extraction of butadiene from the C4 fraction remaining after their ethylene separation. I.C.I. are similarly committed.

The production of various copolymers for special rubber-like substances has been announced by Dunlop Rubber Co. Ltd., Monsanto, at their Ruabon works, and I.C.I., at Wilton. The total capacity of these separate units is said to be 16,000 tons per year.

The largest of the synthetic rubber undertakings announced, however, is that of the International Synthetic Rubber Co. Ltd. This is an organisation formed by the Dunlop, Firestone, Goodyear, and Michelin companies. They plan to build alongside the Esso Refinery at Fawley and to start production at the end of 1957 with a capacity of 50,000 tons per year of general purpose synthetic rubber, the facilities being estimated to cost £8 million.

The butadiene for this undertaking will be produced by the Esso Refinery. This will be the entry of Esso Petroleum into the petrochemical picture in Britain. They state that by 1958 they will be operating a cracking plant with a feed rate of 250,000 tons per year. Although they have made arrangements for supply of materials to the synthetic rubber works this will by no means absorb their complete output. They are therefore prospecting for suitable new customers. It appears that one customer will be Monsanto, who have obtained planning permission and are designing plant to produce polyethylene from the Fawley ethylene. In this Esso differ from the previous operators who had captive markets. Stripped refinery gas will go to the Southern Gas Board.

Future Possibilities

The question inevitably arises as to whether it will be possible to absorb the materials from all this new capacity. The statistics available in the U.K. are insufficient to enable a detailed examination of the trend of the last five years, but from the figures already quoted there appears to be some parallel with experience in the U.S.A., although phased differently in time. Hence, a brief look at the behaviour of aliphatic chemical production arising from petroleum in the U.S.A. will help form opinion regarding the near future in Great Britain.

Over the five year period 1951 to 1955 inclusive, the American production of aliphatics as crudes for chemical conversion almost doubled, rising from 7000 million lb in 1951 to 13,000 million lb in 1955. The greatest increase has been in the production of C2 material, namely ethylene, which has maintained its proportion of one-quarter of all aliphatics produced. Not until 1957 will Britain have reached to one-tenth of the U.S.A.'s 1955 capacity for ethylene, but it will have doubled its ethylene production over 1951. However, the British use of ethylene for the making of synthetic ethanol does not actually represent a completely new accession of resources to the chemical industry, but only a replacement.

In the U.S.A. there has been a very sharp rise in the production of propylene polymers, although the quantities made do not apparently close the gap between the quantity of propylene potentially available and the quantity used. Propylene tetramer production for use in detergent alkylate has increased fourfold over the five year period, rising from 94 million lb to 372 million lb. Alongside this has been the appearance of propylene trimer, entering the statistics in 1953 with a production of 61 million lb, rising two years later to 146 million lb. Propylene trimer is used for the manufacture of nonyl alcohol, important as raw material for the manufacture of plasticisers. Production is already taking place in Great Britain.

Although polypropylene has not yet emerged as a dense, high molecular weight, heat resisting brother of polyethylene, many voices are preparing for its advent as a commercial product. Great things are expected of this new plastic for which a raw material lies to hand.

In the C4 group the principal chemical production in the U.S.A. is butadiene. However, the American experience is perhaps a little difficult for transplantation to the British scene. Up to 1953 the production was steady, but in 1954 came the "denationalisation" of the synthetic rubber factories. There was a drop in demand for butadiene in 1954, but by 1956 butadiene was being hailed as the new petrochemical meteor, displacing both polyethylene and ammonia from the headlines. In 1955 supplies of butadiene were so short that one of the large war-time plants for the conversion of fermentation alcohol to butadiene was reactivated. Whether the new International Synthetic Rubber Co. plant at Fawley has been inspired by this American upsurge or not it would appear that synthetic rubber has yet a long way to go in Great Britain.

Another American expansion which has not yet appeared on the British scene is the large-scale utilisation of the C5 material. In the U.S.A. this entered the statistics in 1952 with a meagre 15 million lb and in four years hit 251 million lb.

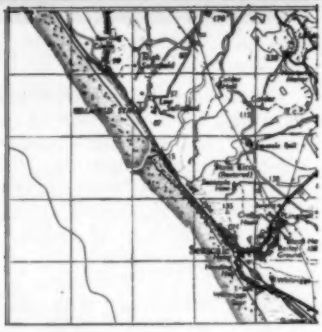
This brief comparison suggests that in Great Britain we may reasonably expect to double the output of chemicals from petroleum over the next five years and that present plans being laid fall somewhat along these lines. But this applies solely to aliphatics.

The Anomalous Aromatics

By virtue of its relatively large coal carbonisation industry, Great Britain differs greatly from the U.S.A. in the shape and development of its aromatics production. No parallel may be drawn. Because of almost complete self-sufficiency in aromatics from coal (with the exception of xylole) there has been little case for petroleum treatment. Hence the description of the British petrochemical industry may pass with scarcely a reference to the subject. However, there are one or two cracks in which petroleum aromatics may lodge, and it will be encouraging to see what the coal carbonisation industry has to offer in reply.

Meanwhile petroleum-based aliphatics have established themselves and have surpassed in importance the long-standing sulphuric acid industry of Great Britain. The new barometer of industrial activity is waiting for the Central Statistical Office to provide it with a dial.

Calder Hall power station (left) lies across the river from Windscale's two plutonium-producing piles (seen on right). In this photo, Calder "A" is nearing completion.



REPORT on

CALDER HALL

by OUR SPECIAL CORRESPONDENT

THE first of Britain's "Model T" nuclear power stations has already been producing electrical power under test conditions, and on October 17 the Queen will switch the output of Calder Hall into the Grid. From then on, Calder Hall, the first truly commercial nuclear plant in the world, will be making its contribution to the electricity supply of Britain—a reversal of the situation which has obtained for the past decade, during which the Atomic Energy Authority has become one of the largest consumers of electric power in the country.

Initially, the power output of Calder Hall will be about 50% of full capacity. There are two nuclear power reactor units of identical design involved—Calder "A" and Calder "B"—and only the first of these has been completed. (Calder "B" is scheduled for completion by mid-1958.)

It was in April, 1953, that the Calder Hall project was first announced in the House of Commons by the Minister of Supply. The intervening period has been one of very great activity on the part of design and site engineers, and of the various contracting firms who have been contributing to this historic achievement. Calder Hall adjoins the Windscale plutonium factory, which has been in production since 1952. A decisive factor in the choice of site was, of course, the proximity of Windscale, with all its available services and its staff of skilled men.

The two graphite-moderated, gas-cooled, natural uranium reactors at Calder Hall are a natural development from the BEPO and Windscale plutonium-producing piles, to cite Sir Christopher Hinton's description. Each reactor unit comprises the following installations: two reactors, 8 heat exchangers, 8 main blowers, 4 turbo-alternators and condensers, 2 dump condensers and 2 cooling towers. Between the two reactor buildings lies the turbine house, which is of conventional design. The essence of the Calder Hall reactor design is indicated in Fig. 1, and the salient features of the gas-cooled reactors was described by Sir Christopher Hinton in his paper to the Geneva international atomic energy conference of August, 1955.[1]

The Calder Hall Piles

The core of the reactor (nominal diameter 31 ft, height 21 ft) contains machined graphite blocks, the weight of which amounts to around 1000 tons. The fuel elements are rods of *natural uranium*; their density is 18.7 g/cc (0.676 lb/cu. in.). The diameter of the rods is 1.15 in. and the length 40 in. They are canned in a magnesium alloy. The cans, which have inside and outside diameters of 1.165 and 1.30 in. respectively, bear helical fins, so that the cooling gas flows in the annulus between the graphite and the fin tips. Because of the modest heat rating of this kind of reactor (in the range 1-2 megawatts per ton of uranium), the capital investment of uranium is large; it has been said that the initial cost of fabricating fuel elements for a power station like Calder Hall "may amount to about £5 million", while a new charge, costing the same amount, would be needed every 3 to 5 years.

The weight of the graphite is supported on a diagrid structure, which consists of an I-section ring girder spanned with steel girders forming a rectangular lattice. (Further details about the mechanical support of the reactor core are to be found in Sir Christopher Hinton's Geneva paper already mentioned.[1])

The fuel elements are stacked in vertical channels in the graphite, which form the flow passages for the coolant gas (which is *carbon dioxide*). The number of channels for fuel elements is 1696. Further vertical channels are provided in the graphite to take the rods for controlling the reactivity of the pile. The graphite structure is to be regarded as consisting of a central core (which houses the fuel elements) and a surrounding neutron-reflector.

Each graphite/uranium pile is contained in a steel pressure vessel, which is a cylindrical shell (of internal diameter 37 ft, height 60 ft) with domed ends. In its turn, the pressure vessel is enclosed in a shield, this time a "biological shield" of thick concrete. The biological shield is 7 ft thick, and rises to a height of about 90 ft. On top of it fits an 8-ft thick concrete roof slab, which completes

General view of Calder "A". The two reactor buildings seen in this picture were constructed on concrete rafts. Calder "B" is scheduled to come into operation in 1958. The total installed capacity of this nuclear power station will be 92 megawatts; between 60 and 70 megawatts will be fed into the Grid, the rest of the power being used by A.E.A. installations.

the biological shielding. This concrete is protected from radiation damage by a "thermal shield" (which comes between the biological shield and the pressure vessel), composed of 6-in. mild steel.

Great care was taken to ensure that the concrete in the biological shield was of high and uniform density—150 lb/cu. ft, as against normal requirements of 145 lb/cu. ft. The aggregate for the concrete was Cumberland Whinstone. A particularly dry mix was used and vibrated after pouring; the weighing of all aggregate, sand, cement and water was very strictly controlled. A wetting agent was used to increase the workability, an important point with a lot water : cement ratio. The actual density achieved was 162 lb/cu. ft. (Incidentally, experience gained on the construction of concrete shields during the construction of the Windscale piles was exploited to the full by the engineers responsible for the Calder Hall job.)

The Pressure Vessel

In his Geneva lecture Sir Christopher Hinton stressed the novelty of the task of fabricating the pressure vessels (which have an internal volume of 57,500 cu. ft) for Calder Hall. The cylindrical shell and the domed ends are 2 in. thick. The fabrication was done on the site, with the sole exception of the inlet manifold. This meant that facilities had to be established at Calder Hall so that the welding could be done on the site. Each vessel was built up into five main sections: namely, the bottom dome, the two parallel centre sections, the diagrid and finally the top dome. As each section was completed it was moved to the lifting area where a 100-ton crane was used to hoist the section and lower it through the roof of the pile vault. The final welds were completed *in situ*. Each and every butt weld was radiographed and all important fillet welds were examined by crack-detection techniques.

The task of relieving the stress in the finished pressure vessel was tackled very seriously, for obvious reasons. Radiant heating, which required up to 1½ megawatts of power, was used to bring the vessel temperature up to rather more than 550°C and this temperature was maintained for 8 hours before the vessel was allowed to cool gradually and evenly.

Then followed the very stringent pressure tests. The pressure of carbon dioxide in these vessels when the reactors are operating is 100 psi gauge. The pneumatic test on each vessel was done at 235 psi. Throughout the test a constant check was kept on the behaviour of the vessel, using strain and other gauges.

The final test was carried out under vacuum at a tenth of an atmosphere pressure. This was done by means of the large rotary vacuum pump which forms part of the operational equipment required for exhausting the vessel when charging or changing the carbon dioxide coolant.

Gas Cooling

The heat generated by fission is extracted by carbon dioxide, the circuit of which is shown in Fig. 2. The ideal gas for cooling would be helium, the order of preference from the heat transfer and nuclear points of view being helium, carbon dioxide and nitrogen. Factors leading to the choice of carbon dioxide for Calder Hall included its cheapness, and its ready availability in Britain compared with that of helium. The coolant circuit contains 25 tons of the gas. Our correspondent was told that the make-up rate has been one ton a day, but the loss is expected to be greatly reduced by the time the plant has settled down to steady operation.

The hot CO_2 coolant (at 336°C) is led away from the top of the pressure vessel by circular mild-steel ducts (4 ft 6 in. in diameter) to the four heat exchangers which are located at the corners of the pile building. The temperature at the lower end of the pressure vessel is 140°C. The cool CO_2 coolant from the base of each heat exchanger is boosted by four main blowers and returned to the inlet manifold at the base of the pressure vessel. Motorised isolating valves of the wedge-gate type are included in each hot and cold

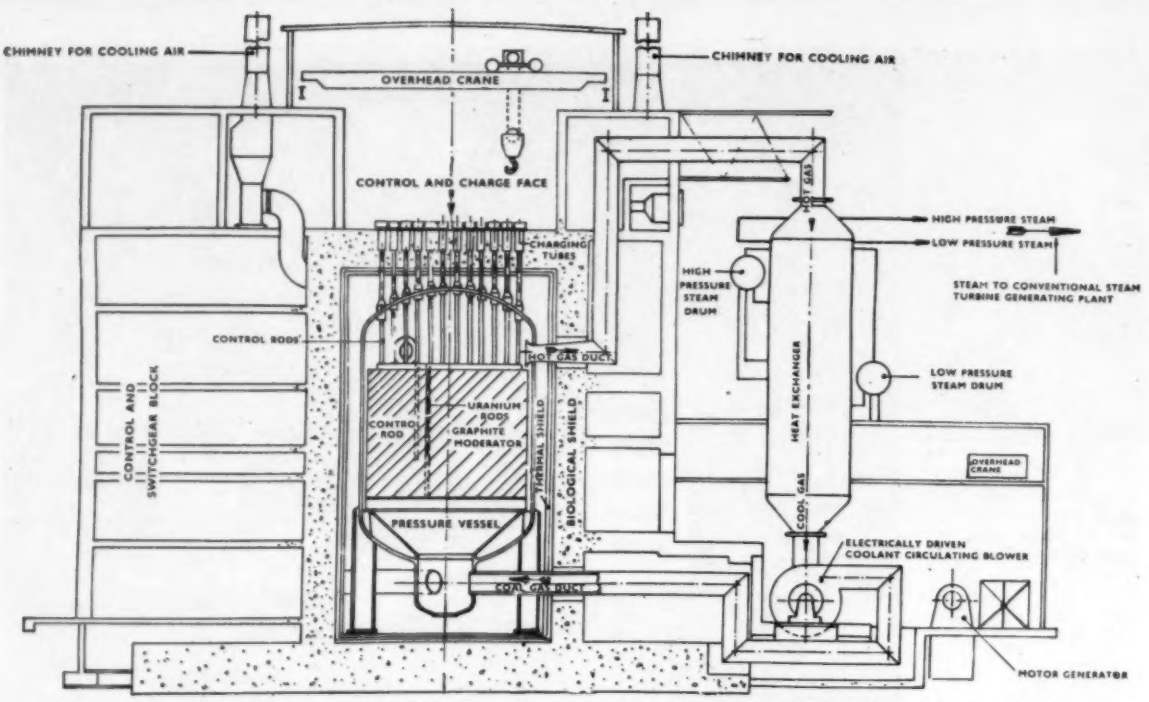


Fig. 1. Shows the salient features of the graphite-moderated, CO_2 cooled reactors. Calder "A" and "B" are identical units; each includes two reactors. Nuclear energy is degraded to heat, which is absorbed by the coolant gas. There are four heat exchangers per reactor to extract heat from the carbon dioxide.

duct, and flow cascades are fitted at the bends in the ducts. To accommodate the large thermal expansions between the pressure vessel and the heat exchangers under various conditions of operation, "hinged bellows" are used in the ducts. The duct flexibility is obtained from the bellows, which are of welded steel plate; the thrust due to the internal pressure of the gas is taken by the pin joint in the bellows assembly. The whole of the duct structures are carried on spring-type constant-load supports (see Reference 1).

The four CO_2 coolant blowers are of the single-stage centrifugal type with an overhung impeller. This impeller arrangement has the advantage of requiring only one gland, but it also has the advantage of facilitating an arrangement in which the gland and bearings can be so located that access to them can be obtained without exposure to radiation which is above tolerance level. The gland is of the face-seal type.

Control of the mass flow of coolant is effected by controlling the speed of rotation of the blowers. The d.c. motors, which develop some 2000 hp each, are supplied from motor generating sets in the blower house, which permit the blower speed to be varied over the range of 10:1 on the Ward Leonard system. About 2% of the mass flow through each blower is taken from the downstream side of the blower, filtered and reintroduced to the system on the upstream side of the blower with a view to preventing accumulation of graphite dust and iron oxide in the coolant system. A constant check is kept on the water content of the coolant, which is kept down by alumina drying units, which hold the dew point of the carbon dioxide below the required limit. As in the Windscale piles, the coolant gas stream is continuously monitored for the detection of burst fuel elements. (In the event of a burst "cartridge" it is thought that it should prove possible to unload and reload the affected channel in a matter of 4 or 5 hours.)

The cooling gas enters the bottom dome through four inlet ducts. It then flows up through the fuel-element channels in the reactor core and is led away to the heat exchangers by four outlets ducts situated above the graphite structure. From each heat exchanger it is returned to the pressure vessel by a centrifugal blower.

The Heat Exchangers

Each of the four heat exchangers is contained in a vertical steel pressure shell of $1\frac{5}{16}$-in. steel plate. They are about 18 ft in diameter and some 70 ft high. Table 1 gives the surface area for heat transfer, the figures referring to the surface (based on the outside of the tubes) exposed to live gas.

Table 1.

High-pressure superheater	4,700 sq. ft 64 elements in parallel (plain tubes)
High-pressure evaporator	31,500 sq. ft 64 elements in parallel (studded tubes)
High-pressure, high-temperature economiser	15,750 sq. ft 42 elements in parallel (studded tubes)
Low-pressure superheater	785 sq. ft 32 elements in parallel (plain tubes)
Low-pressure evaporator	31,500 sq. ft 64 elements in parallel (studded tubes)
Low-pressure and high-pressure economiser	15,750 sq. ft 42 elements in parallel (studded tubes)
Total	99,985 sq. ft

The gas surface of the tubes is extended by elliptical steel studs (see Fig. 3). The final assembly of these heat exchangers was done on the site; each heat exchanger arrived in nine main sections consisting of the dished ends, the six circular centre sections and the skirt. After assembly and inspection, the final welds were stress-relieved, and the heat exchangers lifted on to their concrete plinths using a pair of 100-ton gin poles.

A dual-pressure steam cycle operates at Calder Hall (see Fig. 4). It would have been uneconomical to raise all the steam at a low pressure, since by doing so the

capital cost of the turbo-alternator would have been increased and the thermodynamic efficiency would have been reduced. (The designers of Calder Hall did give consideration to the possibility of using a three-pressure steam cycle—with separately fired superheaters for the high-pressure steam—but they rejected it because of the additional complications it would have introduced.)

The steam goes to the generator house, which is situated between the two pile buildings, where four turbo-alternator sets are installed. Operating details for the turbo-alternators are given in Table 2. Associated with the electrical generating plant are two cooling towers, the make-up water for which is obtained from Wastwater, alternative source being the Calder river. (The feed water system is shown diagrammatically in Fig. 5.)

Table 2.

Number of sets per reactor ...	2
Maximum continuous rating (at a power factor of)	23,000 kilowatts 0.8 lagging
Speed	3000 rpm
Generator voltage	11,500 V, 3-phase, 50 c/s
High-pressure steam pressure at turbine stop-valve	200 psi abs
High-pressure steam temperature at turbine stop-valve	590°F (310°C)
High-pressure steam per set (77% total)	198,000 lb/hr
Low-pressure steam pressure at turbine stop-valve	53 psi abs
Low-pressure steam temperature at turbine stop-valve	340°F (171°C)
Low-pressure steam per set (23% total)	59,300 lb/hr
Output	21,000 kilowatts
Flow rate to condenser per set	257,300 lb/hr
Absolute pressure at turbine exhaust flange	1.75 in. Hg.
Maximum cooling water temperature	85°F (29.4°C)

Processing the Spent Fuel

It will take some time before the operation of Calder Hall becomes fully integrated, but when that stage is reached it is expected that spent fuel elements will be removed at the rate of 30-35 tons at a time. At present the "life" of the fuel elements is expected to be a few months. After removal from the reactors, the highly radioactive fuel elements will be lowered into "coffins" and transported to the Windscale plant for processing. (The separation of plutonium from irradiated uranium was described by G. R. Howells in *British Chemical Engineering*, May, 1956, pp. 8-11.) At the moment, the only material irradiated in the Calder Hall piles is uranium, but once the reactors have settled down it is expected to use the "spare" neutron flux for irradiating other materials.

Fig. 3. A complete tube section of a heat exchanger element made by Babcock & Wilcox for Calder Hall.

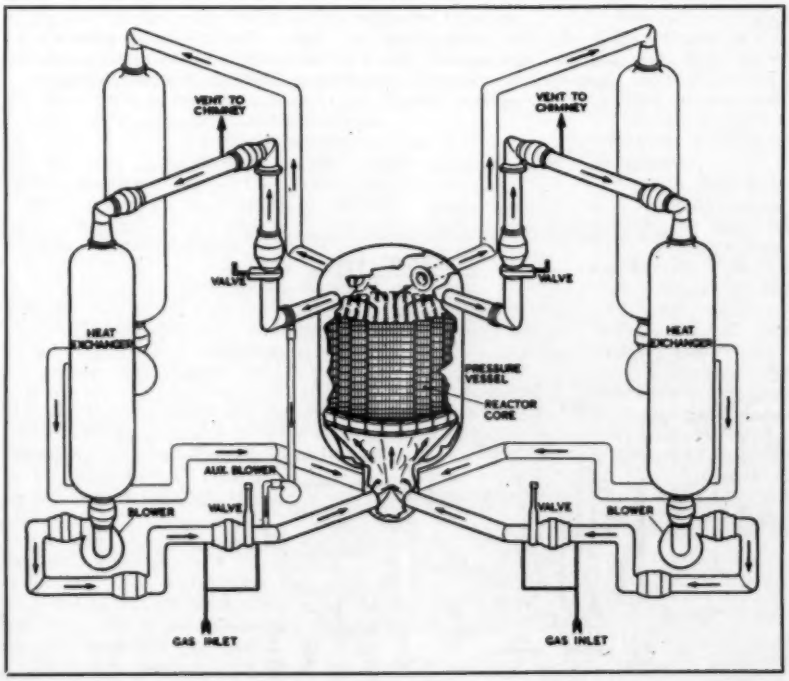


Fig. 2. The gas cooling system. The carbon dioxide circulates at a pressure of about 100 psi throughout the circuit. The temperature at the lower end of the pressure vessel is 140°C; at the upper end it reaches 336°C. From each heat exchanger the gas is returned to the pressure vessel by a centrifugal blower.

An extensive study of the economics of power generation at Calder Hall is being undertaken. The cost per unit of electricity in the early stages is expected to be between 0.5 and 0.6d. The overall efficiency should work out at approximately 20%, which means that *a fifth* of the energy released in nuclear fission is converted into usable electrical power. The figures given in the Appendix indicate how much heat energy can be derived from the uranium and from the "by-product" plutonium.

Appendix

(1) Natural uranium consists substantially of 1 part by weight U^{235} and 140 parts by weight of U^{238}.

(2) In nuclear reactions involving natural uranium and slow neutrons the U^{235} atoms are the ones that are usually split.

(3) When a U^{235} atom is split after absorbing a neutron the nuclear equation is, for example:

$$92U^{236} + oN^{1} \longrightarrow 92U^{236} \longrightarrow 57La^{148} + 85Br^{85} + 3oN^{1}$$

The mass equation is 235.124 1.009 147.961 84.938 3.027

The mass sum LHS = 236.133

RHS = 235.926

The difference in mass = 0.207 unit.

This "boils" off as energy equivalent to $0.207 \times 931 = 193$ MeV—approximately 200 MeV.

Now 1 MeV $= 1.60 \times 10^{-6}$erg.

So 200 MeV, the energy from 1 split U^{235} atom

$= 320 \times 10^{-6}$*erg.*

$= 3.20 \times 10^{-11}$ *watt sec.*

i.e. it requires 3.1×10^{10} fissions/sec. to product 1 watt.

Now in 1 lb of U^{235} there are $\frac{453.6}{235.124} \times 6.023 \times 10^{23}$

$= 11.62 \times 10^{23}$ atoms

Hence if all the atoms in 1 lb of U^{235} were fissioned, the energy released would be

$11.62 \times 10^{23} \times 3.20 \times 10^{11}$ watt sec.

$= 37.2 \times 10^{12}$ watt sec.

$= 10.32$ *million kilowatt hours.*

Alternatively, if 1 lb of U^{235} were fissioned at the rate of 3.1×10^{10} fissions/sec. we would get power at the rate of 1*watt for* 1.032×10^{10} *hr*

Similarly, 3.1×10^{13} fissions/sec would give 1 kilowatt for 1.032×10^{7} hr and 3.1×10^{16} fissions/sec. would give 1 megawatt for 1.032×10^{4} hr.

Now 1 kilowatt hour is equivalent to 3413 Btu; hence the energy released by fissioning all the atoms in 1 lb of $U^{235} = 10.32 \times 10^{6} \times 3413$ Btu.

If the calorific value of coal is 12,000 Btu/lb.

Then if all the atoms in 1 lb are fissioned

1 lb of U^{235} is equivalent to $\frac{10.32 \times 10^{6} \times 3413}{12{,}000}$

= approximately 3,000,000 lb of coal

or 1 ton of U^{235} is equivalent to 3,000,000 tons of coal.

(4) There are slightly fewer atoms in 1 lb of natural uranium than there are in 1 lb of U^{235}. However, the difference is small, so that if all the atoms in 1 lb of natural uranium could be split then 1 lb of natural uranium would also release as much heat energy as 3,000,000 lb of coal.

(5) The complete fissioning of all the atoms in 1 gram of U^{235} will release

$$\frac{3.20 \times 10^{-11} \times 6.023 \times 10^{23}}{235.124} = 8.2 \times 10^{10} \text{ watt sec.}$$

$$= \frac{8.2 \times 10^{10}}{3600 \times 1000} \text{ kilowatt hours}$$

$$= 2.3 \times 10^{4} \text{ kilowatt hours}$$

$$= 1 \text{ megawatt day (approximately)}$$

or 1 gram of U^{235} fissioned per day gives approximately 1 megawatt.

The U^{235} content of 1 tonne of natural uranium is 7000 grams. Therefore, if just under half the U^{235} content of 1 tonne of natural uranium is fissioned, we would get about 3000 megawatt days of energy released.

Alternatively, at present only about half the readily split-table kind of uranium atoms, the U^{235} that occurs to the extent of 1 part in 140 of natural uranium, can be split.

Hence at present 1 lb of natural uranium will only release as much heat energy as

$$\frac{3{,}000{,}000}{140 \times 2} = \textit{approximately } 10{,}000 \textit{ lb of coal}$$

i.e., 3000 megawatt days/tonne.

(6) The reason why only such a low conversion factor can be realised at present is because the atomic ash, the fission products, accumulate in the fuel rods and eventually stop the reaction.

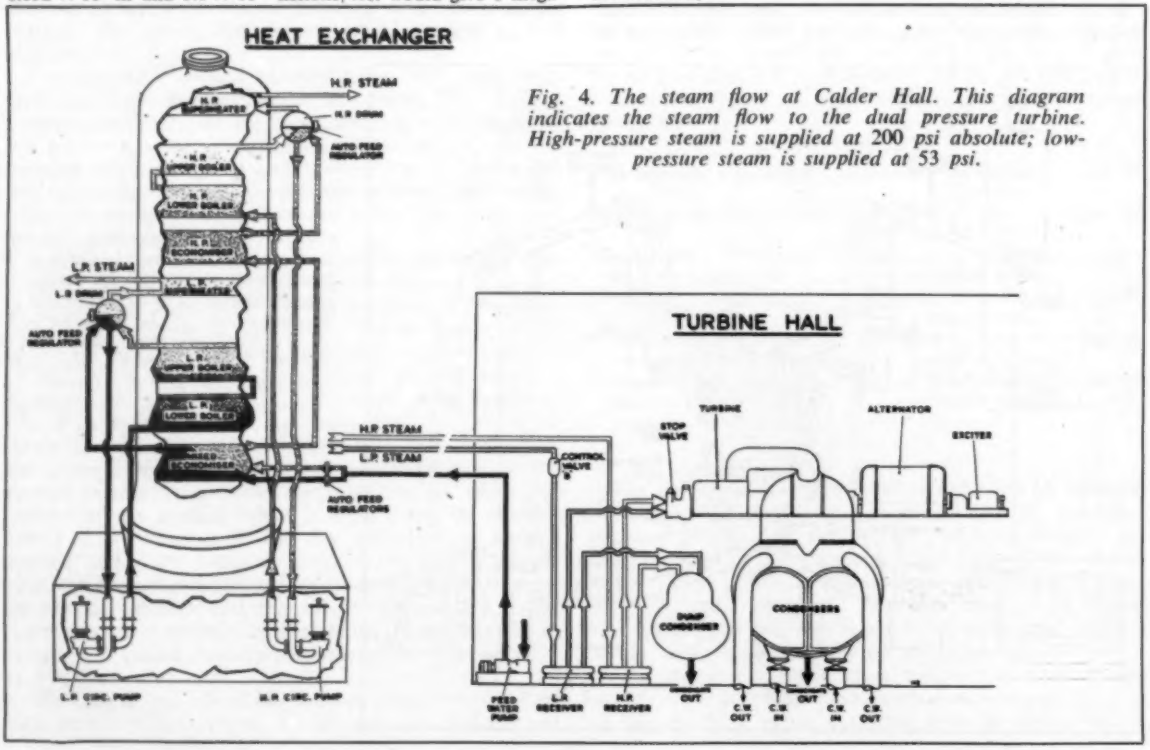


Fig. 4. The steam flow at Calder Hall. This diagram indicates the steam flow to the dual pressure turbine. High-pressure steam is supplied at 200 psi absolute; low-pressure steam is supplied at 53 psi.

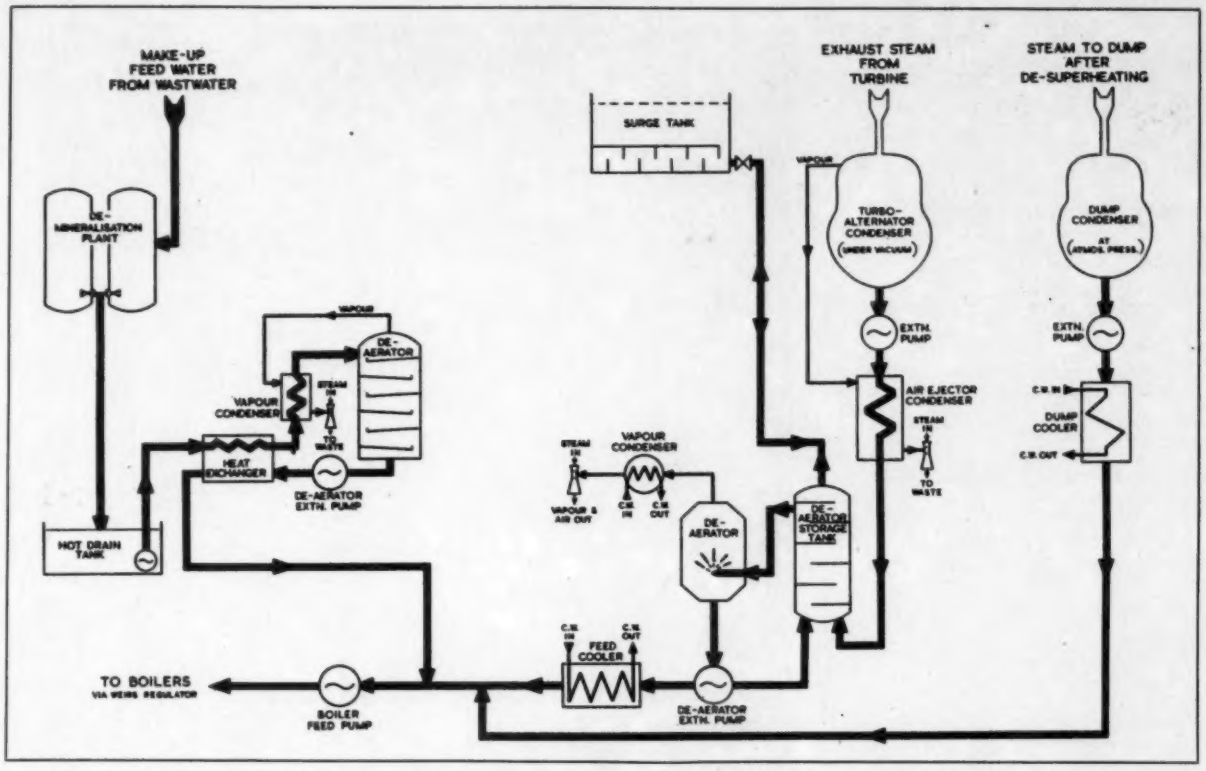


Fig. 5. The feed water system. This includes a demineralisation unit and a de-aerator. The main feed is condensate from the condensers.

(7) When natural uranium is used in a Calder-Hall-type reactor, some of the neutrons (one in every fission) released in a fission reactor are used to carry on the chain reaction. The others either escape or are absorbed by the unsplittable atoms, the U^{238}, and convert it eventually into plutonium, a new element that is also splittable.

(8) If the spent fuel rods are processed and the fission products and the plutonium formed separated, the plutonium being again used in the same reactor, it is estimated that over 1% of the natural uranium can be burnt. In this case 1 lb of natural uranium will be equivalent to 30,000 lb of coal.

(9) To approach the theoretically complete burn-up of all the atoms in 1 lb of uranium, i.e.,

1 lb uranium = 3,000,000 lb coal
= 1 million megawatt days/tonne,

use will have to be made of breeder reactors in which more fuel is produced from fertile material than is burnt.

(10) To illustrate this, supposing 1000 lb of natural uranium were taken and separated into its two component kinds of atom, we would then have

7 lb of U^{235}
and 993 lb of U^{238}.

If the nuclear fire were started in the 7 lb of U^{235}, for every U^{235} atom that split, on average 2½ new neutrons would be produced. One of these would be required for carrying on the reaction and 1½ would be spare.

If the 993 lb of U^{238} were stacked round the nuclear fire of U^{235} the 1½ spare neutrons from the fission could be absorbed in the U^{238} blanket, where they would produce 1½ atoms of plutonium for every 1 atom of U^{235} that split.

(11) When all the 7 lb of U^{235} had been consumed, we would be left with a mass of 982½ lb of U^{238} containing 10½ lb of plutonium.

(12) After separating the plutonium from the U^{238} we could then start a new fire with the 10½ lb of plutonium, stack round it the 982½ lb and produce a further 16 lb of plutonium. So we could go on until all the original 1000 lb of natural uranium had been split up to give us the equivalent of 3,000,000 lb of coal for each lb of uranium.

(13) *Due to losses in processing and other causes, it is not likely that all the uranium will be able to be burnt, but figures of 1 lb of uranium equivalent to 30,000 or 60,000 lb of coal should be readily available in the near future. A figure of 1 lb of uranium equivalent to 1,000,000 lb of coal should be attainable in the future.*

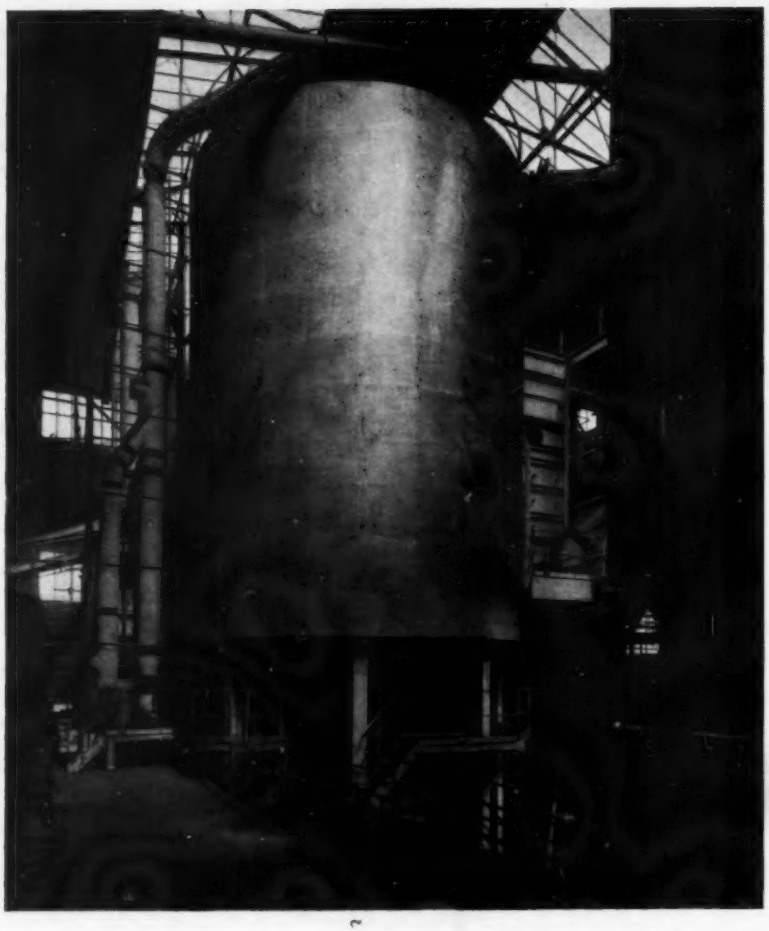
Calder Hall Contractors

The civil engineering for Calder Hall was carried out by Taylor, Woodrow Construction Ltd.; in addition to the normal site work, this firm was responsible for building the biological shields. Babcock & Wilcox made the heat exchangers, and the pressure vessels were constructed by Whessoe Ltd. C. A. Parsons & Co. Ltd built and installed the four turbo-alternators. Other major contractors involved in the Calder Hall project are as follows:

Accles & Pollock Ltd., Aiton & Co. Ltd., N. G. Bailey & Co. Ltd., J. Blakeborough & Sons Ltd., British Acheson Electrodes Ltd., British Insulated Callenders Cable Ltd., Cable Jointers Ltd., Carbon Dioxide Co., Chatwood Safe & Engineering Co., Chesterfield Tube Co. Ltd., Colvilles Ltd., Consett Iron & Steel Co. Ltd., Costain-John Brown Ltd., Crossley Bros. Ltd., Darlington Insulation Co. Ltd., Dewrance & Co. Ltd., Electric Furnace Co. Ltd., English Electric Co. Ltd., English Steel Corporation Ltd., Fairey Aviation Co. Ltd., Alexander Findlay & Co. Ltd., General Electric Co. Ltd., Matthew Hall & Co. Ltd., Hopkinson's Ltd., R. Jenkins & Co. Ltd., G. Kent Ltd., Lloyd's Register of Shipping, Marston-Excelsior Ltd., Mather & Platt Ltd., Metropolitan-Vickers Electrical Co. Ltd., New Western (Engineering) Ltd., Parolle Electrical Plant Co. Ltd., Plessey Co. Ltd., Pollard Bearings Ltd., A. Reyrolle & Co. Ltd., Steel Co. of Wales Ltd., Stewart & Lloyds Ltd., Strachan & Henshaw Ltd., Talbot-Stead Tube Co. Ltd., Wharton Crane & Hoist Co. Ltd.

REFERENCE

[1] Sir Christopher Hinton, "The Graphite-moderated, Gas-cooled Pile and its Place in Power Production," Vol. 3 (Power Reactors), Proceedings of the International Conference on Peaceful Uses of Atomic Energy 1955. (Published by United Nations; distributed in U.K. by H.M. Stationery Office.)



A flash roaster installation used for roasting pyrites in a large sulphuric acid plant in Britain. This device is a precursor to the fluidised roaster. (Photo: Simon-Carves.)

FLUIDISED ROASTING OF PYRITES

THE commissioning of the first fluidised roaster for pyrites to be built in Britain has recently been announced (*British Chemical Engineering*, August, 1956, p. 182). The background to the development of this interesting type of roaster for the sulphuric acid industry and the experience so far gained in its application are worthy of comment, since this particular use of the fluidised technique represents its largest current chemical process application outside the petroleum industry, although by comparison with the latter it is only a midget.

The use of iron pyrites for the preparation of sulphur dioxide for sulphuric acid manufacture represents a change in the previous long trend lasting from the middle 'twenties to the middle 'forties, in which the use of elemental sulphur for acid manufacture was definitely rising. Because of this trend, elemental sulphur constitutes the principal mineral raw material for the manufacture of sulphuric acid today. However, sulphur in its elemental form is not known to exist in reserves of great quantity, and other sources of sulphur from which it is possible to make sulphur dioxide exist in reserves of much greater extent. Of these, the principal member which will produce sulphur dioxide by combustion, without the need of extra fuel, is iron pyrites.

Iron pyrites was first suggested for the manufacture of sulphuric acid in 1818, but it was not employed in Great Britain on an industrial scale until 1839, after the Neapolitan Government (which monopolised the sulphur market) had raised the price of Sicilian brimstone from £5 to £14 per ton. In those days all the acid was made by the lead-chamber process and the substitution of pyrites for sulphur was fairly readily achieved because it was not necessary to undertake much cleaning of the roaster gas. The principal difficulty was to obtain a satisfactory technique for burning the pyrites.

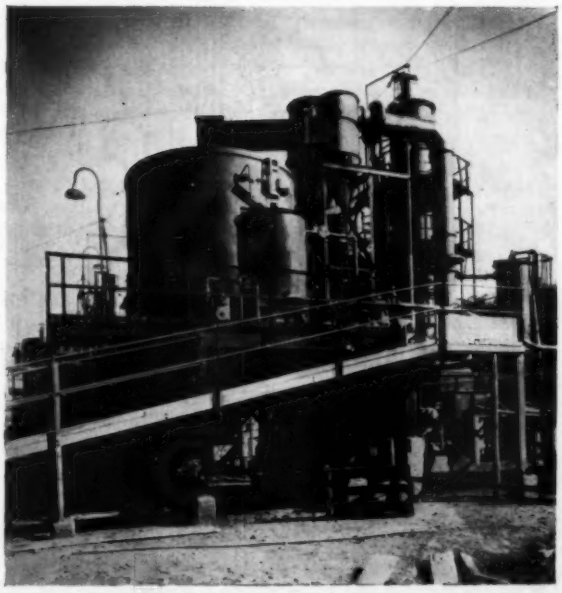
The rise of the contact process for sulphuric acid showed the value of sulphur as raw material. First, it is easy to handle, provided that its temperature is kept in the correct range. Secondly, because gas from a sulphur burner needs little cleaning and no wet scrubbing, the capital cost of the plant required is substantially less than that needed for pyrites burning. This made sulphur-burning plants the best investment.

During the sulphur crisis which prevailed after 1950 the need to install new acid-making plant based on the combustion of pyrites became obvious. At the time, the design of roaster which appeared to be the most suited to the task was the so-called "flash" roaster, which had originally been developed to deal with the supplies of fine pyrites obtained by flotation, which it was impossible to

utilise in previously existing designs of roaster. Although it was not arranged to use flotation pyrites wholly as raw material for these plants, nevertheless some twenty of them were installed in Great Britain and they were provided with grinding equipment so that supplies of massive pyrites could be suitably disintegrated to provide fine material to agree with the handling equipment and flow characteristics of the flash roaster.

The flash roasters fulfilled the demands made on them, but they did not appear to be the ideal method of using pyrites. First, if the raw material was massive pyrites, it meant that an excessive amount of grinding would be employed in order to provide a feed with size characteristics similar to flotation pyrites. In fact, it proved possible to modify this somewhat, but it was still necessary to grind fine. Secondly, the temperature control possibilities of the flash roaster were not satisfactory, because any heat which was transferred had to be removed from the gas phase. Failure to get adequate temperature control led to the formation of agglomerated lumps of cinder which hung in various parts of the equipment and then became dislodged with undesirable results. It seemed, therefore, that the development of the fluidised pyrites roaster would provide the answer to both these problems, because of the known suitability of fluidised beds to handle material at least as large as $\frac{1}{4}$ in., and also because an outstanding feature of fluidised bed behaviour is the high degree of uniformity of temperature throughout the boiling mass of solid.

The first positive step in the industrial use of fluidisation was taken in 1921 when Winkler produced his first gas generator. This laid the foundation for the development of the German brown-coal gasification system which is used today in about twenty plants. In the United States the use of fluidisation in the petroleum industry stems from the work of Odell, which formed the basis of patents applied for in 1935. In the succeeding twenty years the fluidised catalytic cracker, or its equivalent, has become almost an essential part of every major mineral oil refinery. The Dorr-Oliver Company took over the development of the use of the fluidised technique for the processing of minerals and by 1952 had shown the large-scale applicability of the method for the roasting of a number of sulphide ores, including pyritic gold ores, zinc concentrates and iron pyrites. About the same period, the Badische Anilin und Soda Fabrik (B.A.S.F.), of Ludwigshafen, which is in the direct line of descent from the firm in which Winkler carried out his developments, used their techniques for the fluidised roasting of pyrites and installed a considerable amount of equipment for their own internal manufacture of sulphuric acid.



Recovery of uranium from Witwatersrand gold mill tailings requires cheap and abundant sulphuric acid. The acid is prepared from Rand pyrites which is roasted in a Dorrco Fluo-Solids roaster. The above plant was installed by West Rand Consolidated Mines, pioneer S. African uranium producers. (Photo: Dorr-Oliver).

The characteristic features of fluidised roasting of pyrites resemble the general features of all fluidised bed processes:

(a) The bed consists of small particles of solid lifted and agitated by the gas stream but not completely entrained; above the bed is a "dilute phase" of entrained finer particles.

(b) There is great regularity of temperature throughout the fluidised bed.

(c) There is good heat transfer from the bed to cooling elements.

(d) Reaction rates are fast because of the small size of the particles and the intimate contact of the gas stream with them.

(e) It is possible to obtain almost theoretical combustion of the sulphur in the bed with a minimum of air.

Within this realm of similar features there are differences between the approach adopted by the Dorr organisation and that attained by BASF. The Dorr system relies primarily on the use of relatively fine particles and thereby blows air through the bed at low velocities. The BASF system takes over the Winkler method of blowing air at relatively high velocity through the bed and thus obtains a facility for handling particles up to $\frac{1}{4}$ in. in size.

Air Requirements of Roasters

The preliminary sizing of a roaster is determined by the quantity of air it is proposed to use for the combustion of the pyrites. With pyrites of nominal 50% sulphur content it is possible to obtain a burner gas of 15% sulphur dioxide content by volume, and as little as 1% free oxygen. It should be remembered that some of the oxygen from the original air is taken by the iron. For minimum air usage it is therefore possible to assume a consumption of some 167,000 cu. ft. for every ton of sulphur burned. In practice, up to 200,000 cu. ft. might be consumed. After thus determining the quantity of air, it is then required to establish the rate at which the air may be passed through every square foot of the distribution grid of the roaster in unit time. This blowing rate or fluidising velocity is fixed to give satisfactory combustion of the pyrites. This means that the particles of material must be well agitated by the air stream, and that the fine material must be held in the system long enough to provide adequate removal of sulphur. Thus the only reliable method of establishing the linear velocity through the roaster bed is by practical test.

Those people who are familiar with the fluidised bed technique will be aware that it is possible to determine a suitable fluidising velocity without regard to the complete burning-out of sulphur. But then it is necessary to check whether the bed depth is sufficient for burn-out at this particular velocity. In the case of the high-velocity design, where a great deal of the roasting takes place in the gas phase, it is necessary to consider also the effectiveness of the gas space at this velocity.

In the case of flotation pyrites, such as material with a size of 55% through 325 mesh, it is necessary to operate

at a linear velocity of about 1 ft./sec. at 900°C, if it is required to avoid complete carry-over of the calcined fines from the roaster vessel. Such a set of conditions permits a sulphur-burning rate of about 0.13 ton/sq. ft. per day. A method of working at higher rates with flotation pyrites of this original size is to agglomerate the fine material to yield a conditioned feed size of about minus 6 mesh. With such conditioned feed, operating rates with zinc concentrates have been pushed up to about 1.25 ton/sq. ft. per day, with a linear gas velocity of 10 ft./sec. at 1050°C.

In the high-velocity system, although the material may be as large as minus ¼ in., particles below $\frac{1}{32}$ in. are blown out. With such high blowing rates it is possible to obtain the combustion of 1.0 ton of sulphur/sq. ft per day, with a gas velocity of about 8 ft./sec. at 850°C. But, as already pointed out, to obtain satisfactory completion of combustion it is necessary to have sufficient free space and the conditions in this resemble those in the flash roaster. A typical figure for flash roaster capacity is the combination of 0.05 ton of sulphur/cu. ft. per day. When the high-velocity unit is fed with flotation pyrites it is sometimes arranged for secondary air to be added to the free space. When pyrrhotite is used as the sulphur source it is necessary to remember that it evolves sulphur less freely than pyrites and so extra combustion volume is necessary.

The combustion of pyrites with air is an exothermic reaction. Although the heat available may be diminished somewhat by increasing the air delivered to the bed, this effect is not great. The following figures show the available heat from pyrites containing 50% sulphur, taken per ton of sulphur. Temperature levels given are 400°C, which indicates approximately the total heat to be taken out before the gas enters the contact reactor, and 900°C, which indicates the total heat to be taken out of the pyrites roaster before the flue gas leaves, i.e. the amount of heat which has to be removed from the bed in order to control its temperature.

Available Heat per ton of Sulphur (as 50% pyrites)

Strength of Gas—% SO_2	10	13	15.7
B.t.u. available above 400°C	9.6 million	10.4 million	10.9 million
B.t.u. available above 900°C	3.7 million	5.6 million	7.0 million

The primary reason for temperature control when roasting pyrites is to prevent sintering of the iron oxide produced. The magnetic iron oxide which tends to be formed, particularly in the presence of air not greatly in excess of the theoretically required amount, when combustion takes place at about 800°C or higher, is able to sinter by itself when raised to temperatures of the order of 1000°C. This susceptibility to sintering is enhanced in the presence of ferrous suphide because a eutectic of ferrous sulphide and magnetic iron oxide is formed which melts at 978°C. However, in spite of the dangers involved in running at this order of temperature, there is a process advantage obtainable in so far as high temperature favours the formation of SO_2 rather than SO_3. If a wet scrubbing system is employed between the roaster and the contact reactor in order to remove arsenic and hydrochloric acid from the gas stream, then it is valuable to keep the SO_3 low in order to avoid losses of it to the scrubber liquors.

Methods of Heat Removal

Heat has to be removed from the roaster bed in order to prevent sintering, and heat has to be removed from the roaster gas stream in order to present a relatively cool gas to the scrubber or other gas-cleaning equipment. Preferably this heat should be recovered in a useful form. There are a number of ways by which heat may be taken from the bed or by which the bed temperature may be controlled:

(1) Cooled roaster gas may be recirculated. This is intrinsically costly, although practised in the flash roaster system.

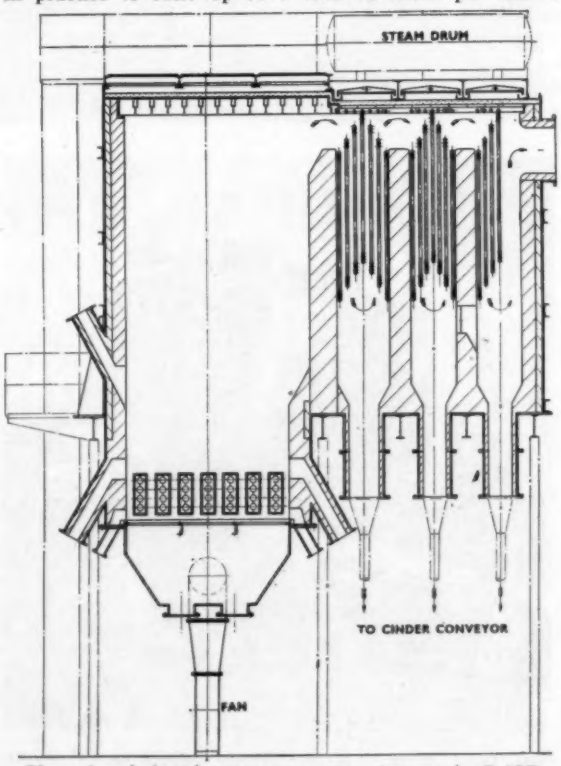
(2) Cooled cinder or cold inert solids may be fed to the bed.

(3) Solid or liquid which is chemically decomposed endothermically may be added provided that the products of reaction do not injure the gas quality. A suitable solid for this purpose is ferrous sulphate. This salt is obtained as a relatively valueless by-product at the factories which manufacture titanium dioxide. By roasting, it is possible to convert the sulphur content to sulphur oxides and leave iron oxide.

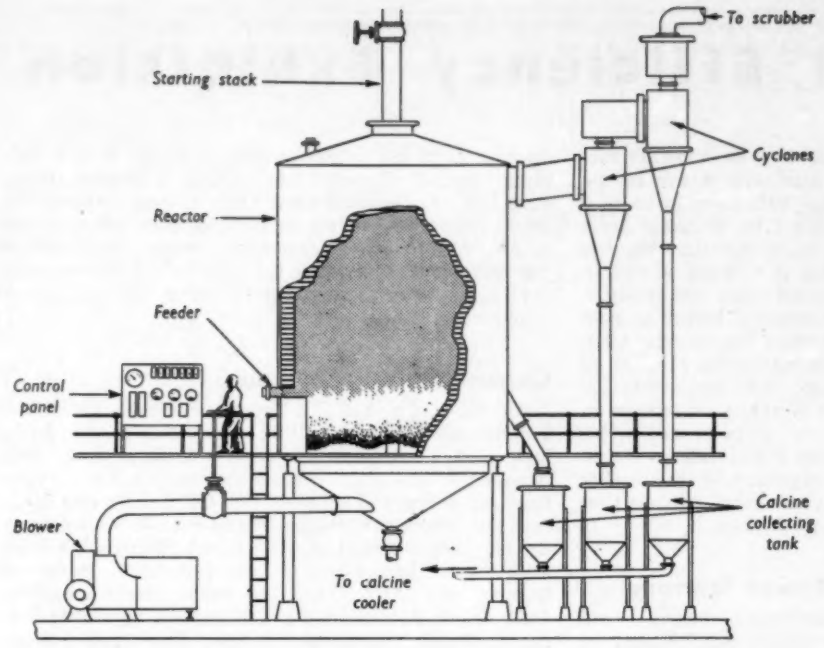
(4) Water is added directly to the bed. Water evaporates very readily in a hot, fluidised bed and provides a means for precise temperature control. Those experienced in fluidised-reactor technique recognise this method as the simplest cooling means available. However, if water is added to a fluidised pyrites roaster it means that some subsequent wet scrubbing system will be necessary and that arrangements must be made for condensing the water evaporated. Furthermore, the water vapour substantially increases the volume of gas leaving the roaster. This has the effect of increasing the load thrown on the subsequent de-dusting equipment.

(5) Water or other heat transfer medium is circulated through jackets, coils or tubes in contact with the fluidised solid.

In most cases it is distinctly valuable to be able to convert the heat which has to be removed into steam. The heat available from the combustion as a whole is sufficient in practice to raise up to 3 tons of steam per ton of



Plan of turbulent layer roaster operating on the BASF (Badische) system. These units can roast from 20 to 120 tons of pyrites per day, and produce gas with a sulphur dioxide concentration of 12-14% with a minimum of sulphur trioxide.



The Dorrco Fluo-Solids Reactor. Ore is fed continuously into the combustion chamber by a screw conveyor. A blower supplies air to roast the ore to a fine calcine which is then blown out of the exhaust, recovered by two cyclone dust collectors in series, and dropped to calcine-collecting tanks. Once started, the fire in the FS Reactor is self-sustaining.

sulphur burned. This steam is developed by cooling the fluidised bed and also the roaster gas stream. Today, the cooling of the bed, in order to raise steam, is done principally by submerged horizontal pipes. The overall heat transfer coefficient thus obtained is between 40 and 50 B.t.u. per square foot per degree F per hour. This figure is in good agreement with the published experimental data. An interesting feature of the bed-cooling system is that in order to control the amount of heat extracted it is necessary to vary the amount of active heat transfer surface. The reason for this is that the temperature difference between the bed and the tube surface cannot be changed very much, and that the heat transfer coefficient is almost constant. Hence the only reliable way to vary the amount of heat extracted is to vary the surface submerged in the bed, or to divert the flow of coolant from some of the tubes. In the latter case some protection is necessary for the tubes and they must be gently cooled; for example, by blowing air through them.

When the fluidised roaster is operated at high blowing rates with pyrites containing a high proportion of fines much of the combustion takes place in the free space. It is difficult to control the temperature in this space. Hence this type of practice is in danger of the same difficulties which beset the operation of the flash roaster, namely the formation of cinder "falls" and blockages.

The recovery of heat from the roaster gas after the completion of the combustion may be done with a suitable water-tube boiler. This was practised with the early Winkler generators and a similar system is still used. A considerable amount of dust is thrown down in the boiler tube space, as is the case with the flash roaster. After the boiler the gas usually passes to a wet scrubber system.

Prospects for Fluidised Roasting

At the present moment the amount of experience in Britain with fluidised roasting of pyrites is strictly limited. With very small pyrites particles, or with difficult materials such as pyrrhotite, burned in a high-velocity roaster there appear to be some drawbacks. On the other hand, the use of the fluidised system for massive pyrites crushed to pass $\frac{1}{4}$ in. lends itself to the high-velocity method.

The relative simplicity of the fluidised roaster—the roaster itself consisting only of a hollow, vertical, refractory-brick-lined, mild steel shell, surmounting a suitable distribution grid set on a windbox—and its small size, e.g. 16 ft. diameter for a cylindrical unit working on the low-velocity principle and handling flotation pyrrhotite at the rate of 75 tons per day, or a rectangular vessel 8 ft. by 9 ft operating on the high-velocity principle and handling 100 tons of pyrites per day, suggests that the fluidised roaster should become a comparatively cheap type of plant. But in spite of the relatively simple nature of the fluidised reactor as such, there is no doubt that with the extra equipment necessary for gas cleaning, and possibly with the sulphur losses arising from the solution of sulphur trioxide in the scrubber liquor, the capital and operating costs will be higher than in the case of the sulphur-burning plant. The only possibility of recouping some of the extra expense is to obtain some value for by-products.

The principal by-product arising from the normal pyrites roaster is cinder or, as it was formerly called, "blue billy". This has some value in the charge material for blast furnaces because it is rich in iron. Unfortunately, the cinder produced by fluidised roasting is small in size. It is therefore only suitable for the blast furnace after it has been sintered into masses. Today, however, there is a steadily growing number of sintering plants being installed in the ironworks of Great Britain primarily for the conditioning of blast-furnace burdens to give greater permeability to the stack gases. It thus becomes more convenient to add a proportion of pyrites cinder in the mix fed to the ironworks' sinter plants. Currently some 400,000 tons of cinder are used in this way each year, equivalent to about 11% of the quantity of imported iron ore used for the same purpose.

Because of the ease with which pyrites may be burned in the fluidised roaster, it becomes more feasible to use the enormous reserves of existing lower-grade pyrites, the more so provided that the ironworks of the country are able to accept the cinder for use in their sinter plants. The development of the use of fluidised roasters, therefore, constitutes a forward step in the more rational use of the sulphur materials available to the world.

The Fuel Efficiency Exhibition

HOW industry can save up to 20% or more on fuel costs and the labour associated with it will be the main theme of the Fuel Efficiency Exhibition to be held at Olympia, London, from October 2-10. In recent years the exhibition has been staged in Manchester, but has proved of such wide interest that it is being moved to London in order to provide increased space and facilities. Held under the auspices of the National Industrial Fuel Efficiency Service and the Combustion Engineering Association, the exhibition will be opened by the Minister of Fuel and Power, Mr. Aubrey Jones, M.P., and will be the largest of its kind ever held in the world. A conference on "the efficient use of fuel in industry", to be opened by Sir Graham Hayman, President of the F.B.I., will be run in conjunction with the exhibition. Organised by the Institute of Fuel, each session of the conference will start at 10.30 a.m. in a hall adjoining the exhibition.

Conventional v Atomic Power Stations

With the eagerly awaited inauguration of Britain's—and the world's—first nuclear power station (see "Report on Calder Hall", pp. 318-323 this issue), the Atomic Energy Authority's exhibit should prove of more than passing interest. Here a working model of the Calder Hall project will be displayed with a detailed cost comparison between nuclear and conventional power stations. The Central Electricity Authority's exhibit, too, will emphasise Britain's leadership in the peaceful uses of atomic energy by displaying information on the Authority's programme for the construction of twelve nuclear power stations by 1965.

From preliminary details released by exhibitors about their products, it is evident that a large majority will make the exhibition the venue for introducing items which fall into "the first time ever" category. Among these are the following: the Watson modulator, a new invention for the control of pressure, temperature, flow, level, composition of fluids, etc. (Combustion Equipment Ltd.); a new method of low-temperature corrosion control applicable to oil-burning practice (Shell-Mex & B.P.); a new helical heat exchanger of compact construction and high efficiency which has unleakable joints (British Boiler Accessories Ltd.); an economical thermal storage boiler of a new type which combines in a single unit the functions of steam-generation and heat-storage (Babcox & Wilcox subsidiary, Edwin Danks); a fully automatic coal and air-feed modulator (Colostat Combustion Systems Ltd.); a draught control for Economic and Lancashire boilers, claimed to be the most advanced of its type (Metropolitan Boiler Accessories Ltd.); three new automatic oil-burning controllers and a new-type thermostatic controller for liquids (The Rheostatic Co. Ltd.); a resonance screen, the largest ever displayed in Britain—7 x 16 ft screening area—and soon to be installed in a northern colliery for coal dewatering duties (West's Gas Improvement Co. Ltd.); low-pressure steam traps based on an entirely new bimetal principle for processes below 40 psi (Midland Industrial Ltd.); a rotary oil burner which is programmed and controlled by an electrical control panel (Hamworthy Engineering Ltd.); and a novel portable belt elevator for use where more elaborate plant is precluded (James Proctor Ltd.).

Air pollution is of increasing concern, both to the general public and industry. Chemical engineers are no less concerned and, likewise, await with interest news of the contents of the proposed Clean Air Bill. The introduction of three new-type smoke-density indicators with ancillary equipments at this exhibition will, therefore, have a wide general appeal (Elcontrol Ltd., Kelvin & Hughes (Industrial) Ltd., Radiovisor Parent Ltd.). In fact, although the varied details of exhibits received at these offices would refute the following statement, these smoke-density indicators will be for many the *raison d'être* for attending this latest recruit to London's long list of annual exhibitions.

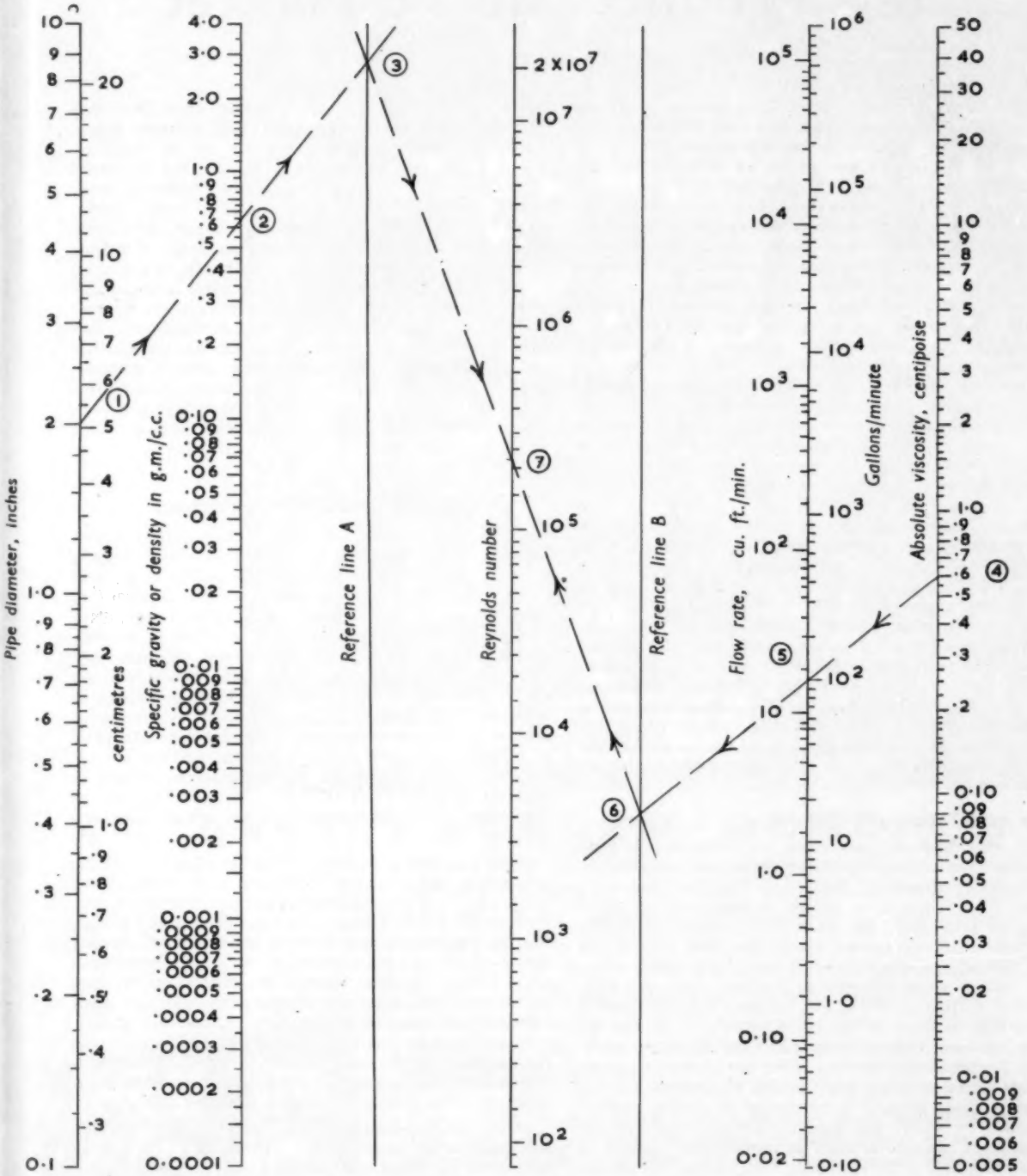
Other Exhibitors Include:

Aeromatic Co. Ltd.; Ashworth & Parker Ltd.; Auto Combustions (London) Ltd.; Airheating Ltd.; Bailey Meters & Controls Ltd.; Barter & Sons Ltd.; Bells Asbestos & Eng. Ltd.; Bennis Combustion Ltd.; Joshua Bigwood & Son Ltd.; The Birtley Co. Ltd.; Keith Blackman Ltd.; Black Automatic Controls Ltd.; F. A. Borchardt; British Doby Stokers Ltd.; The British Electrical Development Assoc.; British Iron & Steel Federation; British Oil Burners Mfrs. Assoc. Ltd.; The British Steam Specialities Ltd.; British Rototherm Co. Ltd.; British Standards Institution; British Thermostat Co. Ltd.; The British Vacuum Cleaner & Eng. Co. Ltd.; Brockhouse Heater Co. Ltd.; Brown Fintube (Gt. Britain) Ltd.; Calomax (Engineers) Ltd.; Cambridge Instrument Co. Ltd.; Charrington Gardner Locket (London) Ltd.; The Chimney Construction Co. Ltd.; Cochran & Co., Annan, Ltd.; Copes Regulators Ltd.; Copperad Ltd.; Crane Ltd.; Crosthwaite Furnaces & Scriven; Danfoss Manufacturing Co.; Darlington Insulation Co. Ltd.; Davey, Paxman & Co. Ltd.; Davidson & Co. Ltd.; D.S.I.R.; Dewrance & Co. Ltd.; Electroflo Meters Co. Ltd.; Elliott Bros (London) Ltd.; Esso Petroleum Co. Ltd.; Evershed & Vignoles Ltd.; Fibreglass Ltd.; Fina Petroleum Products Ltd.; Flexible Drives (Gilmans) Ltd.; G. W. B. Furnaces Ltd.; The Gas Council; The General Electric Co. Ltd.; James Gordon & Co. Ltd.; E. Green & Son Ltd.; Harris Eng. Co. Ltd.; John E. Harrison Ltd.; Hemel Hampstead Eng. Co. Ltd.; James Hodgkinson (Salford) Ltd.; Honeywell-Brown Ltd.; Hopkinsons Ltd.; Hurseal Ltd.; Hydran Products Ltd.; Imperial Chemical Industries Ltd.; Industrial Pyrometer Co. Ltd.; International Combustion Ltd.; IVO Engineering & Construction Co. Ltd.; Kelly & Mahler Ltd.; Kitsons Insulations Ltd.; Lancaster & Tonge Ltd.; R. F. Landon & Partners Ltd.; Lea Recorder Co. Ltd. Leeds Meter Co. Ltd.; Joseph Lucas (Hydraulic & Combustion Equipment) Ltd.; Measurement Ltd.; Metropolitan-Vickers Electrical Co. Ltd.; Mirrlees Watson Co. Ltd. Moorsden Ignition & Accessories Co.; Morgan Refractories Ltd.; J. & J. Neil (Temple) Ltd.; Newalls Insulation Co. Ltd.; Newton Chambers & Co. Ltd.; Niagara Eng. Co. Ltd.; Nu-Way Heating Plants Ltd.; Perkins C.M.E. Ltd.; Peal Controls Ltd. Prat-Daniel (Stanmore) Ltd.; Permutit Co. Ltd.; Potters' Insulations Ltd.; Prior Stokers Ltd.; Peabody Ltd.; The Quickdraw Co. Ltd.; Thomas de la Rue & Co. Ltd.; Rubery, Owen & Co. Ltd.; Ruston & Hornsby Ltd.; Senior Economisers Ltd.; Shanden Scientific Co. Ltd.; Spirax-Sarco Ltd.; Sprayed Insulations Ltd.; W. F. Stanley & Co. Ltd.; Steam Storage Co. Ltd.; Stemco Ltd.; J. Stone & Co. (Deptford) Ltd.; Sunrod Ltd.; Tangyes Ltd.; Tellus Super Vacuum Cleaner Ltd.; Thermal Efficiency Ltd.; P.H. Thermal Products; Thermodare (Gt. Britain) Ltd.; John Thompson Ltd.; John I. Thornycroft Co. Ltd.; Ronald Trist & Co. Ltd.; Turbine Furnace Co. Ltd.; Versil Ltd.; Wallsend Slipway & Eng. Co. Ltd.; Watts Automatic Boilers; Zwicky Ltd.

NOMOGRAM FOR DETERMINATION OF REYNOLDS NUMBER FOR FLUID FLOW CALCULATION

This nomogram should be used in conjunction with Nos 3 and 4 (August and September, 1956, issues).

EXAMPLE: d=2in., S=0.65, Q=100 gpm, μ=0.60 cp.
By nomogram, $Re = 2.1 \times 10^5$
By calculation, $Re = 2.06 \times 10^5$



The basic equation is: $Re = \left(\frac{SQ}{\mu d}\right) 3790$

where S = specific gravity or density in gm/c.c.
Q = flow rate, gallons per minute
μ = absolute viscosity in centipoises
d = pipe diameter in inches
Re = Reynolds number

AMERICAN LETTER

New Products Go To Market

by Dr. Lincoln T. Work

THERE is a vast array of new compounds coming from chemical companies. The small manufacturer in particular is overwhelmed by the possibilities available to him; and often he does not have the personnel or the facilities to select the promising new materials or to adapt his techniques to their application. Nor is it enough for research teams to prepare new compounds to become commercial items. Estimation of markets and product development for customer applications are themselves a business, vying in magnitude with research and development.

During the period from the early twenties to World War II, the annual number of new products available to the industry was only a few per cent of the number presently being offered. It was a popular practice to describe the nature and properties of these compounds on the advertising pages, and then to sit back and wait for inquiries. While individual circumstances may still warrant that procedure, there is now a far stronger follow-up of inquiries resulting from advertising. More especially, the producing company makes an effort to introduce the product directly to a particular industry. To do this convincingly, the producer must become familiar with his customer's field, and must visualise the way in which his product can be used. If he can show its superiority on economic or quality grounds, he is well on the way to being in business in this product.

The Commercial Chemical Development Association, the Chemical Market Research Association, and the new division of Marketing in the American Chemical Society are all active organisations bringing together people who work in this area. The rapid rate of growth to their present substantial sizes are indicative of the changes which have taken place in introducing new products to the market. A few case histories will serve to illustrate these activities.

Tin and Titanium Chemicals

Roughly 7,000,000 pounds of tin chemicals are being produced annually in the United States, according to Mr. Herbert Hirschland of Metal and Thermit Corporation, New York. There is a variety of such products which range in price from fifty cents to five dollars per pound. De-tinning affords a good source for these, because the wet methods employed serve to yield a high-grade of tin and because some intermediate products, also quite pure, serve as starting materials. The company had established a substantial business in tin oxide opacifier, and this led them into new business in antimony and zirconium opacifiers. The electronic business called for ceramic materials having special dielectric qualities, and bismuth stannate has found a place there as a component of barium titanate mixtures in which the bismuth stannate stabilises the capacitance against variation in temperature. Because of their know-how in tin chemicals, they became the natural company to work with Proctor and Gamble in developing stannous fluoride for tooth paste. Organo-tin compounds first developed to stabilise polyvinyl chloride, are used with the arochlor transformer oils, in silocone curing, in deworming agents, and in controlling slime in the paper industry.

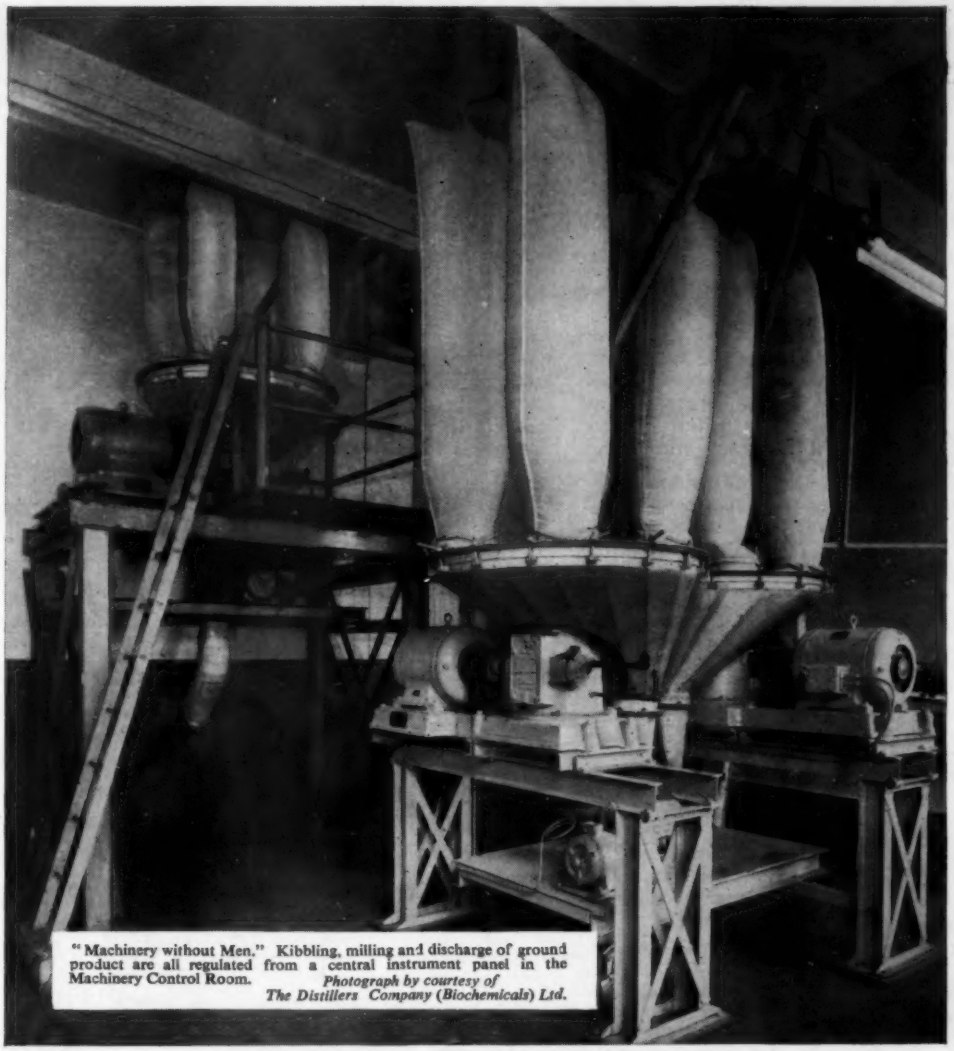
Mr. W. B. Anderson, of Titanium Pigment Corporation, a division of National Lead Co., New York, has told of the development of titanium pigment which has high covering power and is inert. The calcium-based titania largely displaced lithopone because of its qualities. Recently a non-chalking grade of pigment was developed that made possible a vast array of light colours for automobiles, so that a black auto is now a rarity. Paper, ceramics, light coloured roofing granules are fields now benefiting from the qualities of titanium oxide. A first try in gem rutile has been abondoned in favour of strontium titanate which will need market development in the unique jewellery trade. It is also being tried in lens systems. Organic titanates have been publicised through advertisements and have received an unexpectedly large response for uses not anticipated by the producer. A new powder material, titanium dichloride diacetate has been found effective as a flame retardant for cellulosic textiles. Alone it retards well, and combined with antimony trichloride it gives flame retardancy even after repeated launderings.

Chemicals for Uranium Extraction

As is often the case, the costs of concentrating a lean ore and of extracting the valuable materials with good yield and satisfactory purity limits the quality of ore that may be used. Dr. R. A. Foos of Electro Metallurgical Co., a division of Union Carbide and Carbon Corporation, Niagara Falls, N.Y., has described the efforts in securing extractants for uranium. Liquid extraction, now well advanced in development, seems likely to replace ion exchange for recovery of uranium and vanadium from acid solutions. This involves two liquid phases. A number of organic phosphorus compounds have shown results, chief of which are di(2-ethyl hexyl) phosphoric acid and trioctyl phosphine oxide in kerosene. After extraction, the soluble salts are removed from the oil by an alkaline wash. A number of long-chain amines have also proved useful for the extraction.

There has been a demand for cerium, thorium, and the rare earths, which has been badly out of balance with the percentages of each occurring in the source minerals. Mr. S. Becker Treat of Lindsay Chemical Co., West Chicago, Ill., has pointed out uses of these materials: arc lighting carbons which contain a rare earth mixture, the pyrophoric metal used in cigarette lighters, the production of alloy and stainless steel, treatment of filter cloths with rare earth solutions, the lens and mirror industry, coloured glasses, and cerium oxide polishing abrasive. Efforts to move the rare earths into the steel industry are under way and, if successful, this application would call for a substantial enlargement of production in this industry.

There are numerous publications in market research and commercial development. One which stands out on account of its origin and the ground of its coverage is a book entitled "Successful Commercial Chemical Development," edited by H. M. Corley, and available to you through Chapman and Hall, Ltd. It is noteworthy because it is the group effort of a substantial number of people in the Commercial Chemical Development Association and each chapter was prepared under the auspices of a committee specifically selected for that purpose.



"Machinery without Men." Kibbling, milling and discharge of ground product are all regulated from a central instrument panel in the Machinery Control Room. *Photograph by courtesy of The Distillers Company (Biochemicals) Ltd.*

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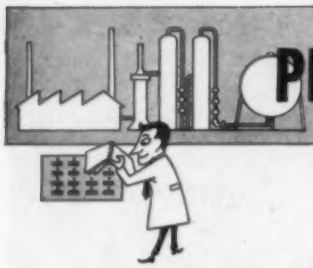
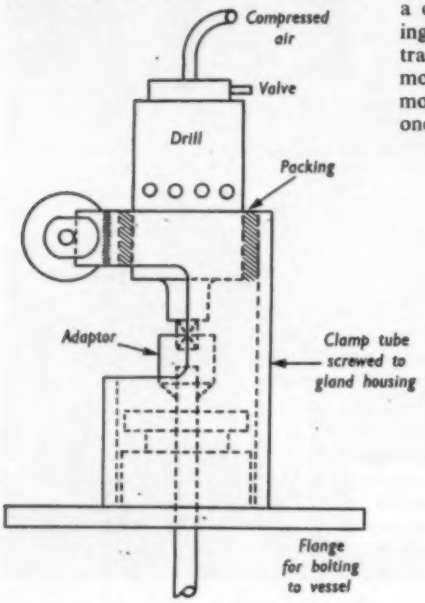


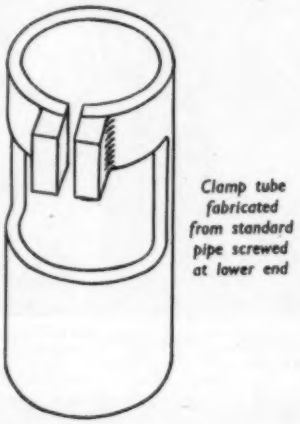
PROCESS ENGINEER'S NOTEBOOK

Compressed-air-operated Agitators

SOME PROCESSES, such as batch-wise processes involving complex organic liquid-phase chemical reactions, require the premixing of reactants, usually of a few minutes' duration, before their introduction into the reaction equipment. For example, if one set of reactants consists of volatile alkylamines dissolved in a medium such as chloroform, some mixing will be necessary in order to give a solution of uniform composition for feeding to the next stage of the process. In such cases a fire hazard will also arise, since the alkylamines are inflammable. The premixing vessels will therefore require flameproof equipment. If the agitation can be successfully accomplished by means of a low-speed propeller (around 500 rpm), the usual type of electric motor need not be used; a compressed-air motor may be used instead. If a number of reactants require premixing—the case if a series of similar products is to be manufactured consecutively—then one motor may be used for a group of premixers. This kind of installation will require much less initial outlay than an all-electric flameproof system of starters and motors, it will require less labour to assemble and, provided intermittent stirring only is required, will be inexpensive to operate.

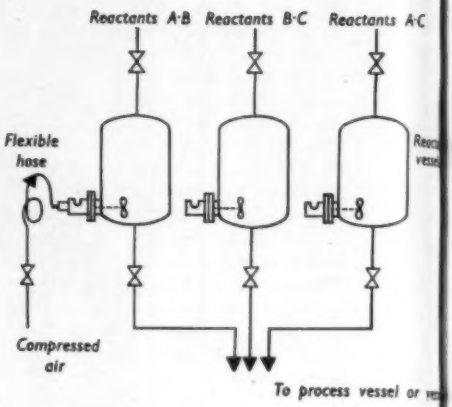
A compressed-air drill will provide a cheap and reliable motor for driving the agitators—up to ½ hp can be transmitted. A special design of mounting is required to allow the motor to be readily removed from one vessel to another.





A diagram of a typical installation is shown together with a design for the motor mounting. In the latter, a piece of internally-threaded tube is screwed on to the agitator gland housing. An alternative method of construction employs a socket screwed on to the gland housing into which the main tube is, in turn, screwed. The tube has a cut-away for inspection of the gland and shaft coupling, and is split at its top end in the manner shown. On the other side of this division two pieces of square section bar are welded. These ends are pulled together by means of a special clamping bolt (e.g., a Lindaptor) to secure the motor to its mounting.

Packing cushions of soft rubber are attached by an adhesive to the upper part of the tube to accommodate eccentricity of the motor and driven shaft. Care must be taken not to block the drill head exhaust holes in the fitting, and on the agitator shaft a thrust shoulder or race should be provided to prevent movement of the shaft into the vessel. The drill is supplied with compressed air via a length of flexible hose sufficient to allow ready connection to all vessels. The outside diameter of a compressed-air drill will normally be less than 2 in., so that a very compact assembly can be made. The idea is satisfactory for vessels of 350 gal. capacity, but should only be used where intensive agitation is not required. With smaller vessels the intensity can be increased.



Self-priming Attachment for Centrifugal Pumps

THIS SELF-PRIMING attachment was observed during a recent visit to the Derby Works of International Combustion Ltd. It is a simple, non-mechanical device useful where fluids to be pumped are slurries or clear liquids. For operation with the former, however, it is sometimes necessary to drain the pump if it has to be shut down for prolonged periods. The attachment consists of a simple ejector fitted into a cylindrical container, with a small-bore tube connecting the discharge line with the inlet to the priming chamber. The system of operation is as follows:

(1) The priming chamber is filled with water and the pump is started.

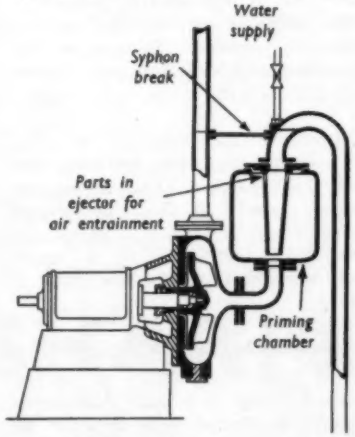
(2) The liquid is thus drawn out of the priming chamber, causing a partial vacuum to be created there. As a

result, air in the suction line is drawn up into the priming chamber.

(3) Eventually all the air in the suction line finds its way into the chamber and, by the displacement caused by the flow of more liquid into the chamber and by the suction at the ejector ports, mixes with the fluid and passes through the pump to the delivery lines.

(4) The air is thus finally removed from the chamber and the pump is fully primed.

(5) On closing down, the liquid will flow back into the vessel or sump from which it was previously being pumped, until the by-pass from discharge to suction is uncovered. The syphon is thus broken and the pump



and chamber are left ready for a further start-up. The pump may occasionally have to be drained on stopping, or it may lose the priming liquid through leakage. Water or other priming liquid may be added to the chamber through the valve in both instances.

A Safe and Labour-saving Tipping Bucket

THIS IDEA, developed by the Alkali Division of the I.C.I., has been used for handling chemicals such as soda ash. Its advantages of greater safety and labour saving suggest a wide use where bulk solids such as sulphur, lime, etc., are handled by means of overhead lifting machinery. Discharge of the older type of bucket required the services of a man at ground level who had the job of attending to the tipping and return actions. The modified bucket eliminates the necessity for manual operation, as the alterations make it possible for a crane driver to carry out the unloading and returning actions from his cab: this without the need for additional controls in the cab. The following explanatory details of the modified bucket, in conjunction with the diagram, will enable readers to grasp the manner in which the bucket performs its function.

Detail of Trunnion Pin

Manufactured from 2¼ in. diameter mild steel bar, 4 in. long, one end is screwed 2⅛ in. of its length, 1⅛ in. Whitworth thread, which passes through the handle, secured with a nut and locked by an ⅛ in. split pin; on the opposite end of the trunnion pin a ⅛ in. thick, 2¼ in. diameter head is left to fit behind the "C" slot plate, which secures the handle to the bucket. The 1 in. of pin between the head and screwed end is turned to 1¼ in. diameter; this rides inside the "C" slot.

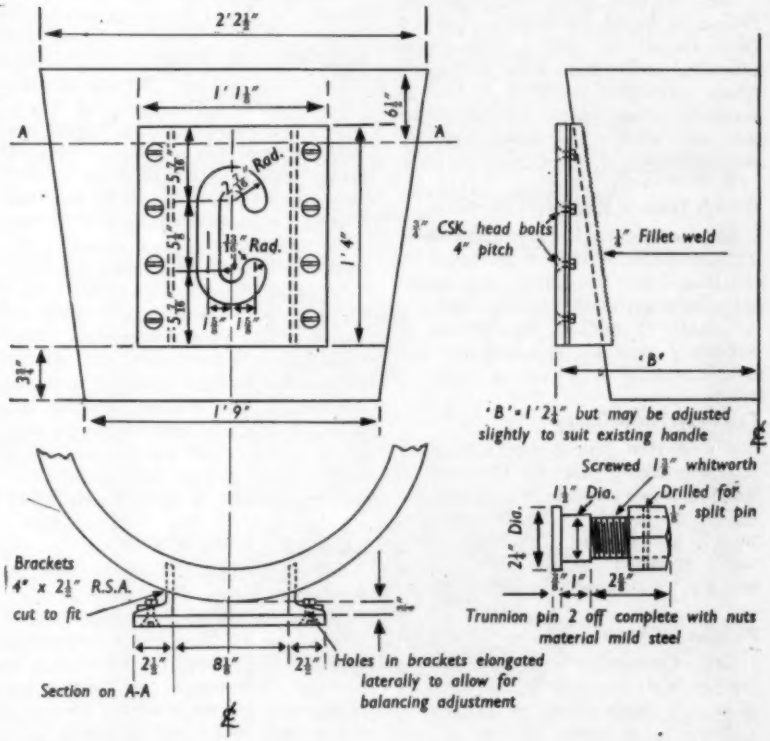
Detail of "C" Slot Plate and Bracket

Manufactured from mild steel plate and roll steel angle, the plate (16 in. x 13¼ in.) into which the "C" slot is cut on the centre line is secured with ¾-in. csk. head bolts to 4 in. x 2½ in. R.S.A. brackets, which are cut and welded to the bucket side to bring the plate into a vertical plane.

Detail of Tipping Action

When the bucket is lowered by crane to a standing position, by slewing the jib and lowering the handle the trunnions will slide into the bottom of the "C" slot; a slew of the jib in the opposite direction before lifting and the trunnions will slide into the new point of balance. When the handle is lifted the tipping action is effected and the bucket will hang upside down. To reverse the bucket to its normal position the tipping procedure is repeated.

A catch (not shown on the photograph) has been fitted to each "C" slot plate which allows the handle to be left in a vertical position when the bucket is not in use.



World of Chemicals

Austrian Oil Plant

Europe's most modern grease unit forms part of a new Austrian lubricating oil installation which has recently come into operation. Planned in 1950, the installation will enable Shell Austria A.G. to manufacture 75% of the products it requires for home markets using indigenous raw material almost exclusively.

Dutch-African Nylon Plant

Tricotbest N.V., the Dutch textile concern, are to establish a nylon stocking factory in the Union of South Africa.

U.S.S.R.'s Coal Shortage

Mr. Khrushchev, criticising the failure of Soviet collieries to reach a coal target of 430 million tons annually, said that there were too many engineers working in offices instead of at the coal face. "Altogether too much energy was being expended on paper instead of on coal," he said.

British Cement Record

Sir George Earle, in a review of 1955, announced record deliveries by the Blue Circle Cement Group (which includes British and Alpha companies) of about 9¼ million tons. Value of exports earned for this country was over £14 million.

Czech-Syrian Refinery

The Syrian public works minister has announced that the Czech firm, Techno Export, has been awarded the tender to build an oil refinery in Syria. British and American firms were reported to have submitted tenders for this refinery.

Persian Oil Strike

The Government-owned national Iranian Oil Company's new well at Qum, 75 miles south of Tehran, is gushing to a height of 200 ft and flooding the surrounding desert. Strict fire precautions are in force and the Persian Government has requested assistance from the International Oil Consortium for equipment to cap the gusher. Reports state that the well is flowing at a rate of 80,000 barrels daily, which would make the well the biggest producer in Persia.

Australian Bauxite Find

A find of several hundred million tons of bauxite in Australia is reported by Miners Consolidated Zinc.

New Carbon Black Plant

Mr. John Waddell, chairman of Amalgamated Anthracite Holdings, in his statement accompanying the accounts for 1955, states that the company's American associates recommended the introduction of plant for making the standard Kosmos/Dixie tyre blacks. Control was acquired of United Kingdom Chemicals and United Carbon Black as a prerequisite to advancing the money necessary for this capital expenditure.

U.S. Ethylene Oxide Plant

Plans to build an $8 million ethylene oxide plant near Baton Rouge, La., have been announced by Wyandotte Chemicals Corporation, Wyandotte, Mich.

Salk Vaccine for Export

Secretary Sinclair Weeks, of the United States Department of Commerce, announced during August the establishment of a strictly limited export quota of one million cc for Salk poliomyelitis vaccine for the balance of the third quarter, 1956. This represents approximately 2.5% of production for May, June and July.

Secretary Weeks said: "Now that supply is approaching domestic requirements, an allocation of vaccine is being made for commercial export to friendly foreign countries urgently in need of the vaccine. During the period when the supply was short, only small amounts of the vaccine were licensed for export for special purposes, primarily in the research field."

B.P.'s Second Test Well

B.P. has begun a seismic survey in south-east Sicily. This follows other intensive geophysical and geological surveys of the company's concession areas on the island. Their object is to provide information on which to choose the site for a second test well. B.P.'s first test well in Sicily was drilled near Vittoria in 1953/4. Some crude oil was found, but of such low quality that efforts to find a commercial use for it were unsuccessful.

French Sugar Refinery

The construction of the new sugar refinery being built at Jacob, in the Niari Valley half-way between Brazzaville and Pointe Noire, has made rapid progress and production is scheduled to begin in October. This refinery, which will process sugar cane grown on a concession of 7,500 acres in the immediate vicinity, will have an annual rate of production of 10,000 tons of refined sugar sufficient to meet almost the whole of the present requirements of French Equatorial Africa. A new town with a population of 8,000 is to be built to house the factory and plantation workers.

Brazil's Chemical Factory

A consortium of three large concerns of Swiss chemical manufacturers, Sandoz, Ciba and Geigy, is to build a chemical factory next year at Rezende in the state of Rio de Janeiro. There is no information as to the nature of the chemical products to be manufactured, although it is stated that production is expected to begin in 1959.

Pakistan Dyestuffs Factory

The Pakistan Industrial Development Corporation have announced that the dyestuffs factory proposed to be set up under their agreement with the Bayer and Hoechst companies, of Germany, will be at Daud Khel, where a cement factory, a fertiliser factory and the U.N.I.C.E.F. penicillin factory are already situated.

Supra Red Oxides

Arrangements have been completed for Golden Valley Colours Ltd. to take over the manufacture and sale of Supra Red Oxides previously made and sold by I.C.I. The trade has been informed that orders for these products should be sent to Golden Valley Colours Ltd., Wick, Bristol.

Hungarian Oilfield Ruined

According to the Hungarian Communist Party newspaper *Szabad Nep*, the oilfied at Nagylengyel, Hungary's main source of domestic oil, has been ruined by excessive exploitation. The newspaper report stated that water had got into the wells because production had begun on the basis of exaggerated estimates of reserves. Even today the reserves were not accurately known. The newspaper further stated that new wells should be sunk and new oilfields developed. Prospecting had begun to the north and north-east of Nagylengyel, it added.

Arabian Oil Royalties

The Finance Ministers of Jordan, Syria, Lebanon and Saudi Arabia met recently in Damascus to consider the American Trans - Arabian Pipeline Company's offer to divide 50% of its profits as royalties among the four countries. The pipeline crosses the territory of all four countries. Purpose of the meeting was to decide what proportion of the royalties each will accept.

It staggers even us ...

. . . to find out how many jobs the Sharples Super-Centrifuge will do

When the Sharples Super-Centrifuge was first designed no one could ever have imagined the amazing range of problems it would ultimately solve.

Day after day we are asked to look into difficult separation problems that did not exist only a few years ago. It's surprising how often the ideal answer is the Sharples Super-Centrifuge. The jobs range from antibiotics to soap, from fish oil to hush hush jobs about which our lips are sealed.

Uses for this machine are growing so fast because it is today's most effective means of separating liquids from liquids, clarification and purification. It will effect separations that are impossible by other means, due to the very high centrifugal force generated in the Super-Centrifuge. This Sharples machine operates continuously and so can be used in continuous flow processes. Cleaning is so simple that the machine can be running again in 15 minutes.

We at Sharples provide a complete technical advisory and testing service on all separation problems for the Super-Centrifuge and our range of other types of continuous centrifuges. And because we are the only people able to supply a complete range of centrifuges for every separation purpose, our advice is always unbiased.

Why not find out more about the Sharples Super-Centrifuge and our other equipment by sending for Bulletin No. 1259M or, if you wish, phone Amberley 2251/3 and talk to Martin Trowbridge about your problem.

The rotor of the Sharples Super-Centrifuge has only 3 parts and the complete unit occupies very little floor space.

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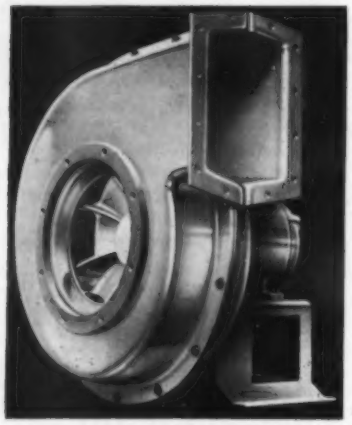
SHARPLES CENTRIFUGES LTD., WOODCHESTER, STROUD, GLOS. *Telegrams : ' Superspin,' Stroud*

PLANT EQUIPMENT NEWS



Range of PVC Fans

Keith Blackman have announced details of their new range of PVC fans, series 1 and 2. The former, the company states, should be in production within a month or so, while the latter, series 2, is immediately available. The fans, designed for fume removal, are constructed in rigid PVC, resistant not only to fumes from various chemicals, but to those from aqueous solutions of nearly all inorganic salts in all concentrations at temperatures up to 120°F. Series 1 and 2 fume removal fans together offer the widest range of sizes and duties in plastic fans available in the United Kingdom. Keith Blackman undertake, also. the accurate design and manufacture of hoods and ducting in rigid anti-corrosive PVC material. **Keith Blackman Ltd., Mill Mead Road, Tottenham, London, N.17.**

BCE 399 for further information

New Argonarc

British Oxygen announce the introduction of the Model C automatic Argonarc welder. Electronic control plays an important part in this machine and brings complete automatic control to Argonarc welding for the first time. The machine is intended for welding jigged components and for the welding of cylindrical sections formed from flat sheets of metal. The main feature of the machine is automatic arc-length control, which is obtained by a welding head with a vertical travel of 16 in. This will follow curves and undulations on the workpiece, at the same time maintaining an exact distance between the arc and the joint, ensuring a uniform weld deposit with controlled penetration. Excellent welds on very light gauge material and on circumferential sections are also guaranteed with this head. Water, gas, current and other controls are operated from a remote push-button control panel, and once the correct welding conditions are set no further action on the part of the operator is required during the welding sequence. **British Oxygen Gases Ltd., North Circular Road, Cricklewood, London, N.W.2.**

BCE 400 for further information

New Driving Head

The Panther 30 is one of a range of new driving heads for heavy industrial use, where reliability is the first essential and where any breakdown may involve losses in output or adversely affect continuous processes. The first characteristic of the machine is its robust design, yet overall dimensions are relatively small and the machine is easily accessible for maintenance and cleaning.

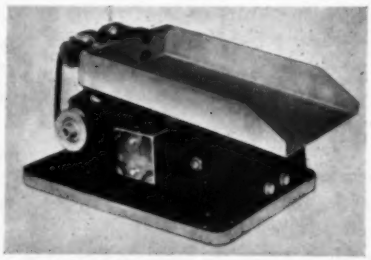
The driving drum is 27 in. in diameter, and is cambered along its face to assist in tracking the belt. A 12-in. diameter snub drum is fitted to increase the belt wrap, thereby decreasing the operating tension in the belt. The head is so arranged that a belt line of up to 21 degrees from the horizontal can be accommodated. The motor is spigot mounted to the gearcase, with the first reduction pinion keyed to the motor output shaft, thus dispensing with a separate coupling and increasing the efficiency of the drive. The speed reduction is through a double train of high-grade hardened steel gears mounted on ball bearings in a cast-iron gearbox. The final reduction wheel is keyed directly to the driving drum shaft.

The side frames and snub frames are of heavy fabricated steel construction, connected by cross ties and mounted on a baseplate constructed of rolled steel channels and plate to form a braced box section. A machined projecting face is provided on the top of the baseplate to form a location for the gearcase and side frames, so as to ensure positive alignment for the drive under all conditions of site assembly. **Richard Sutcliffe Ltd., Horbury, Wakefield.**

BCE 401 for further information

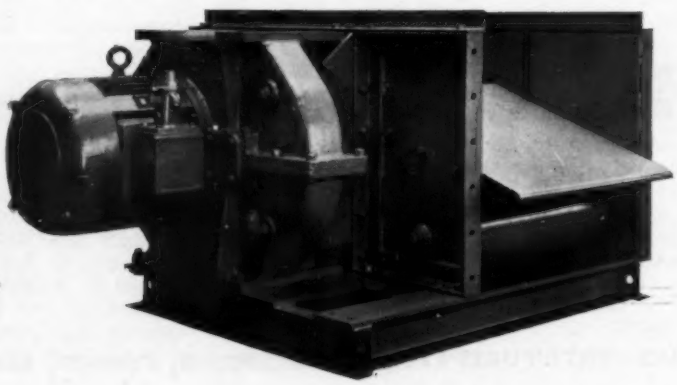
Vibrating Feeder

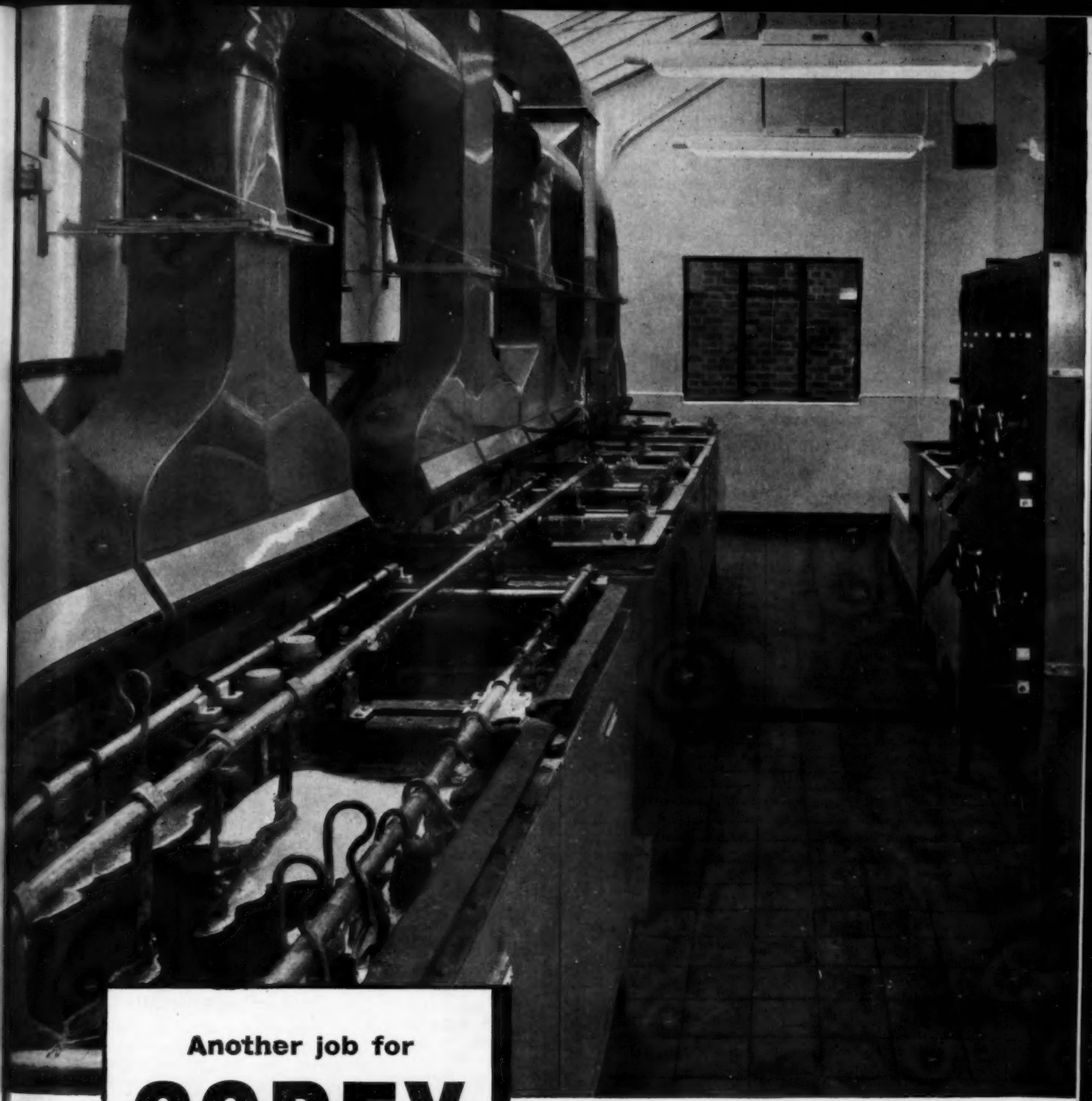
Details of a simple and robust mechanical unit with a wide range of adjustment giving feed rates between a



few pounds per hour and a maximum which varies according to the nature of the material being handled and the feed-tray width have recently been forwarded to us by The 30-98 Co. Ltd. A typical maximum rate is 4 tons per hour of provender meal weighing 35 lb./cu. ft on a 9 in. wide tray.

The vibration is produced by an out-of-balance weight assembly driven by a fractional horse-power motor. The amplitude is variable by bringing the feed tray forwards by a spring into gradually firmer contact with a rubber buffer. The tray-supporting member strikes the buffer at the forward end of its stroke so that the rearward acceleration of the tray is





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RIGID VINYL SHEET

No other synthetic construction material combines the chemical resistance of COBEX with such ease of fabrication and low manufacturing cost

WHEREVER resistance to chemical corrosion is of prime importance, COBEX Rigid Vinyl Sheet—non-absorbent, easily fabricated and dimensionally stable—is the obvious material to use. At the Weybridge demonstration plating department of the Electro-Chemical Engineering Co. Ltd., the extraction ducting is made entirely of COBEX. Installation by Prodorite Limited, Artillery House, Artillery Row, S.W.1.

BX PLASTICS LTD

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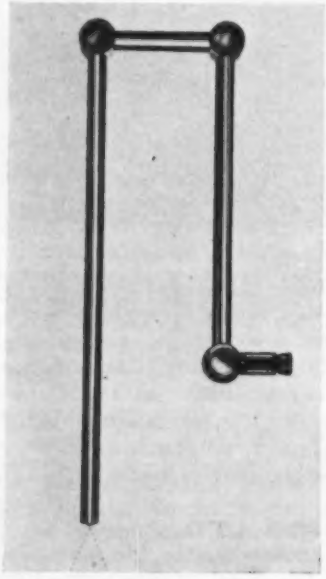
much higher than in the forward direction. This impact effect produces much higher conveying rates than simple harmonic vibration. Control is normally made by a pointer arm moving in a quadrant. Remote control can be arranged by fitting a small reversing motor to operate the pointer arm. Similarly, automatic control units can be arranged to alter the rate of feed through a small reversing motor. The machine is supplied with four flexible mountings, and may be installed on wooden floors or a steel frame without affecting its performance. **The 30-98 Co. Ltd., Gatwick House, Lowfield Heath, Sussex.**

BCE 402 for further information

Industrial Periscopes

Bodson Periscopes are intended for use in industrial installations where normal visual examination of objects or phenomena is impossible, due either to their situation or attendant dangers. They are normally installed as part of the plant and equipment. Applicaions for the Periscope include the examination of dangerous chemical plant (including explosives processing); boiler water-level gauge viewing, observations of models in wind tunnels, visual observations of aircraft controls in test flying, etc. In addition to the above, one of the most common is for observation inside atomic reactors and in radioactive processing plants. In such cases the Periscopes can be made entirely of stainless steel and with cerium stabilised, radiation-resistant, glass lenses.



The normal diameter of the Periscopes is approximately 1.2 in. and maximum total length approximately 25 ft. A variety of bends can be introduced as can be seen from the illustration. The field of view is normally 45 to 50 degrees, but magnifications up to eight times are possible if the angle of view is reduced to 6 degrees.

P. W. Allen can also supply Endoscopes, which are portable instruments for the internal examination of all forms of hollow components such as pressure vessels, pipe-work, condenser tubes, evaporator tubes, etc., where corrosion may lead to serious trouble and failure. The lengths of Endoscopes vary according to the diameter and all sorts of interchangeable objective heads are available, giving vision at the end of the Endoscope at a variety of angles to the normal line of sight.

Instruments of this type require specialised service and P. W. Allen offer technical assistance and advice on such visual-inspection problems. **P. W. Allen & Co., 253 Liverpool Road, London, N.1.**

BCE 403 for further information

Miniature Thermostatic Valve

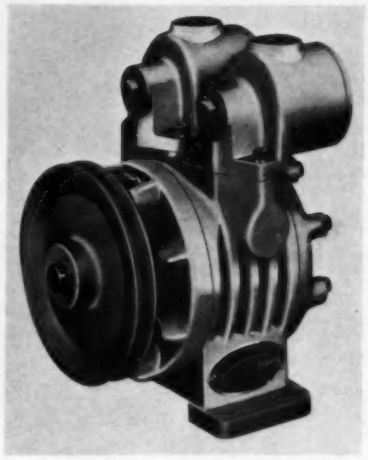
A new miniature thermostatic valve of the self-acting modulating type has been introduced by Teddington Industrial Equipment Ltd. This new valve is of very small dimensions and is intended for the control of small unit heaters, sterilisers, warming ovens, etc. It is suitable for use with steam or hot water up to a maximum pressure of 150 psi and is available with either $\frac{5}{16}$-in. or $\frac{1}{4}$-in. seat, the body being tapped $\frac{1}{2}$-in. B.S.P. Alternative temperature ranges cover the extremes of 55 and 230°F. The new valve is known as the type WO. **Teddington Industrial Equipment Ltd., Sunbury-on-Thames, Middlesex.**

BCE 404 for further information

New Rotary Pump

Lacy-Hulbert & Co. Ltd. have recently introduced a new model of their RB2 Mark II rotary pump. This is completely oil-free. While previous models have been relatively free of oil, no pump so far has achieved this absolute state. The RB2 Mark II rotary pump is used for continuous operation at vacua up to 25 in. Hg and pressures up to 10 psi.

The pump has interesting constructional details. There are no pistons, springs or valves; the self-seating



vanes are of a composition which will operate dry and lubrication is therefore unnecessary. All parts are interchangeable; they are manufactured to fine limits and subjected to inspection before each complete unit undergoes test. **Lacy-Hulbert & Co. Ltd., Boreas Works, Beddington, Croydon, Surrey.**

BCE 405 for further information

Fire Detection

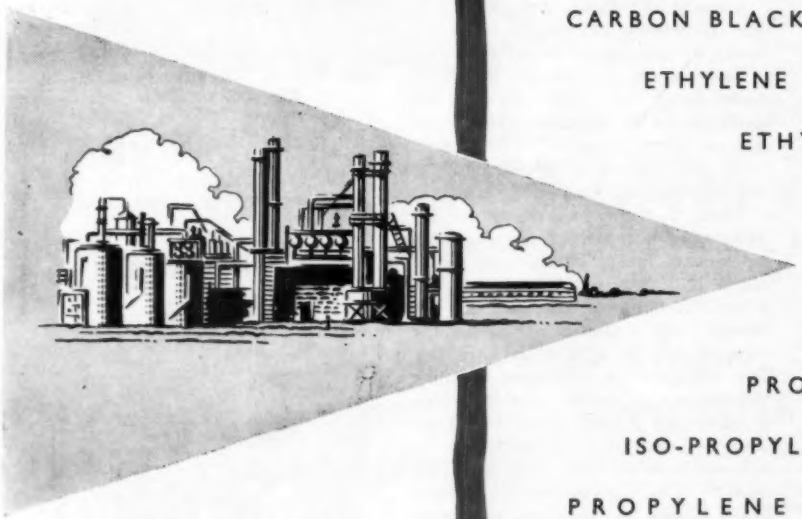
A fire-detection system which is constantly undergoing modifications to ensure that it does incorporate every known advance in fire detection is the Auto-thermatic. Briefly, the system consists of heat detectors, which are sensitive to rapid temperature change, central control panel and alarm bells. Connecting cables, too, are heat sensitive to exposure to flame (giving under-flooring protection) and provision can be made for the system to be directly connected to a fire station. **Sound Diffusion (London) Ltd., 243-247 Coastal Chambers, 164 Buckingham Palace Road, London, S.W.1.**

BCE 406 for further information

Protective Overalls

H. Bednall have forwarded a photograph to us which illustrates an employee of the Atomic Energy Authority, Harwell, wearing a Bednall leather protective overall. Bednall state that the body of the coat is made from vegetable-tanned skirting leather, which is comparatively stiff in order that the garment shall hang in as vertical a position as possible. The reason for this is that if sodium is splashed on to this overall, it will not adhere except when it lodges in a fold of the material. The sleeves are made from a natural full-chrome unmordanted leather, which is considerably more flexible than that used for the body section. This is to allow for free movement of the arms. As it

Chemicals and Petrochemicals



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PLANT EQUIPMENT NEWS

was found by experiment that sodium very quickly attacked any outside stitching, the stitching has been kept to an absolute minimum and the joins, which are necessary in view of the limited size of the skins, are arranged to face downwards wherever possible. Solution is used in place of stitching in most of the seams and in addition, every seam has a strip of leather solutioned on the inside to prevent any penetration through the seam. The latest model has elastic inserted in the edge of the left upper forepart in order to prevent the formation of any pocket. The helmet and cape, as well as the boots shown in the photograph, are also made from the leather which is used for the sleeves. **H. Bednall, Eldon Street, Walsall.**

BCE 407 for further information

Wave Pulse Generator

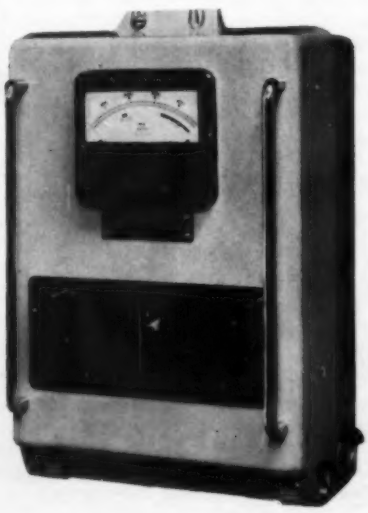
A new wave pulse generator has been announced by D.F. Developments Ltd. as the direct result of over four years of research into wave and sonic energy transmission through liquids.

The new machine, known as the Sonomec Energy Generator, is primarily intended for use in laboratories. The apparatus is a mechanical vibrator with great variability within the frequency range of 0 to 200 c/s. It consists essentially of a mechanically driven disc diaphragm which transmits vibrations to either liquids or solids placed in the 1-gal. capacity processing pot of the apparatus. The linkage mechanism incorporates a means of adjusting the amplitude of vibration in a variable manner. Frequency also can be varied without stopping the machine. **D.F. Developments Ltd., 2 Clement's Inn, Strand, London, W.C.2.**

BCE 408 for further information

Nucleonic Level Indicator

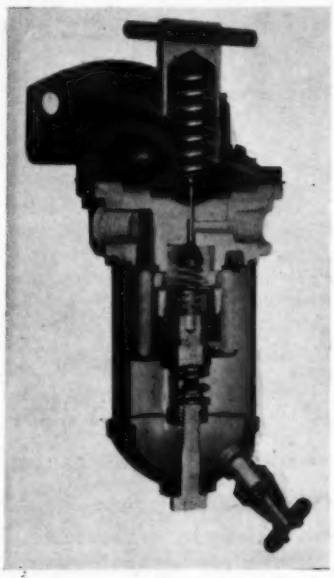
A new level indicator which makes use of gamma radiation has been announced by Baldwin Instruments. In this a gamma-emitting isotope is placed on one side of a container and a detector on the other. Radiation passes from the isotope, through the container to the detector which is, in fact, a geiger counter. The output from the detector is proportional to the amount of radiation which it receives. In other words, when the contents of a container are below the radioactive "beam", maximum radiation will be received by the detector. When the contents rise and cut the "beam", the radiation reaching the detector will be substantially smaller. The difference in radiation reaching the detector is shown as a difference in electrical output from the geiger counter, and this is arranged to operate a relay. The indicator unit shown in the accompanying photograph houses the relay and two lamps which indicate whether the "beam" is broken or not. Baldwin's state that it is a relatively simple matter to incorporate the relay in some automatic control circuit. For complete control, two heads can be fitted to the container, thereby giving indication when the contents reach both maximum and minimum levels. Alternatively, a movable head can be fitted so that the "level" can be determined at any given time. As the operation of the relay is dependent in the first instance on the *difference* in radiation, it is possible to detect the boundary between, say, two liquids having substantially different densities. This is simply because the lower the density, the greater will be the amount of radiation which will pass through. The equipment in both the detector and the indicator unit are housed in robust, dust-proof, metal cases and are fitted on anti-vibration mountings. This instrument should go a long way towards meeting most of the requirements of level indication and control. **Baldwin Instrument Co. Ltd., Brookland Works, Dartford, Kent.**



BCE 409 for further information

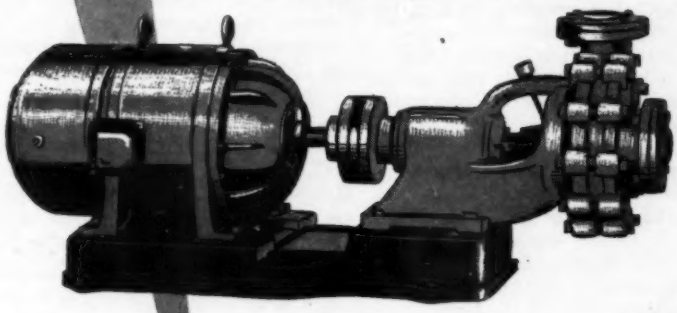
Air Filter Set

The Crosby Mason Neilan No. 74 air set combines the features of drip-well, 50-micron ceramic-cartridge-type filter, tight shut-off reducing valve and relief valve, all in one robust, compact unit. This instrument will provide an extremely stable air output in spite of wide fluctuations of supply or demand, or against dead-end service. The filter element can quickly and easily be replaced by undoing only one bolt and one nut. Light alloy and steel have been completely eliminated from the all-brass body, which is rated at 250 psi. **Crosby Valve & Engineering Co. Ltd., Crosby Works, Ealing Road, Wembley.**



BCE 410 for further information

PUMPS FOR THE CHEMICAL INDUSTRY



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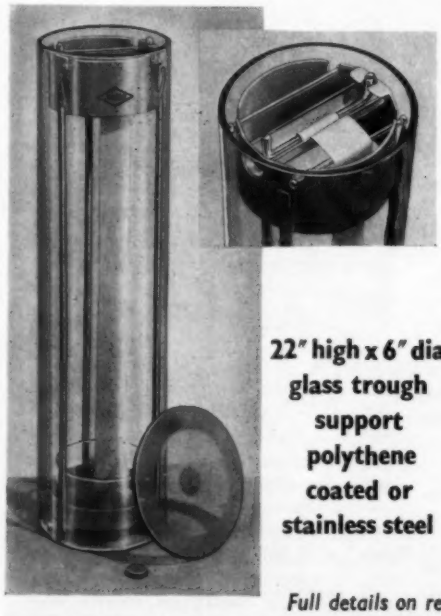

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Book Reviews

The Life of Ludwig Mond.

by J. M. Cohen

Methuen, London, 1956. 295 pp. 22s. 6d.

A BIOGRAPHY of Ludwig Mond was probably overdue. He has been dead nearly fifty years and his achievements have been overshadowed by the industrial empire-building of his son. He was one of the real founders of modern chemical industry and a pioneer of the transition from batch to continuous processes. The basis of his success was the realisation that Solway's process for soda would supersede the Le Blanc process, although he had begun by attempting to solve the problem of sulphur recovery from the alkali waste.

This book, gives a fascinating story of the accidental steps that led a young German Jew to found several chemical industries. Ludwig Mond was born in 1839 in Cassel and grew up in the ferment, social and intellectual, which accompanied the revolution of 1848. He was educated at the Polytechnic and at Marburg University under Kolbe. It was the background of chemical business in the family that launched him, at first as a kind of consultant in the chemical plant business. His first venture on his own account was the acquisition of Winnington with John Brunner to set up an ammonia-soda plant. It was Mond who made all the calculations of process economics, designed the plant and supervised its construction. He was a real prototype chemical engineer, who met the specification of the late Hugh Griffiths with "the ability to calculate accurately and resourcefully". He not only developed his soda works but pioneered producer gas and the production of nickel from the carbonyl.

The book also gives a pointer to the opposition in I.C.I. to chemical engineering for so long. If Mond had continued in his early ways, the Society of Chemical Engineers would not have become the Society of Chemical Industry when he was appointed one of the four honorary secretaries in 1871. He became too impressed with the virtues of pure science. In a speech at Manchester in 1895 he advised the students to give all their attention to the study of pure science without any thought for immediate practical results. His own generation had been too quick to lay down their textbooks, and translate what they learnt into terms of works chimneys and waste tips. This conclusion was the result of his familiarity with this emphasis in German education at the time. The success of German chemical industry seemed to drive it home, although that had its mainspring in the whole philosophy of the German General Staff to concentrate industry and to integrate the economic life of the country for an expansionist policy. It was Alfred Mond who was to learn that lesson from the 1914-18 war and to take the steps with MacGowan which led to the formation of I.C.I., and to immortalisation by T. S. Eliot:

I shall not want capital in Heaven
For I have kissed Sir Alfred Mond.
We two shall lie together, lapped
In a five per cent. Exchequer Bond.

Ludwig's dictum on pure science lasted for too long. One hopes his biographer is not trying to caricature Winnington Hall as he describes it today. "From the University comes the informality of dress: corduroy trousers, the bright rowing club tie, the sporting cap. It is from the Universities that this group of men have been drawn, and particularly from Oxford and Cambridge." This is not a fair picture to put beside the 24 year old Ludwig in Holland. For £15 a month with a bonus of £200 when work was completed and production going on for three months, he undertook to produce a fixed quantity of sodium sulphate, hydrochloric acid, soda ash, soda crystals, chloride of lime, sulphuric acid and sulphur, from an equally fixed quantity of pyrites, salt, chalk or limestone and manganese dioxide of given composition. The choice of plant and general arrangement, as well as the selection and use of labour, were in his hands. That picture is worth a great deal and one can only be grateful to Mond's biographer for the personal and family details and regret that there was no room for setting him more firmly in the economic history of this times.

Oxygen in Iron and Steel Making.

by J. A. Charles, W. J. B. Chater and J. L. Harrison.

Butterworths Scientific Publications, London, 1956. 291 pp., 42s.

OXYGEN has come like a breath of fresh air to the steel makers. Not only is it showing them how to increase output per furnace, but also it is making them think hard how it will act at any stage of interest in the manufacture. In most cases it is not possible to state precisely how much the production will be changed by the use of oxygen, because steel making has some of the qualities of brewing beer, in that a routine has been established from which only the most daring are prepared to make any but small departures, covering a succession of interlocked and parallel processes.

The present book brings together in an informative and informed manner the many results of trials and experiments made in the steel works of the world. The substance included in the volume comprises most of the possible applications of oxygen.

The book is set out in three sections. The first deals with the use of oxygen for the removal of metalloids from molten metal. This section opens with a short theoretical discussion of the thermodynamics of metalloid oxidation and derives the theoretical oxygen requirements and the temperature rises to be expected. The application of this theory is then considered in terms of de-siliconisation of iron, the use of oxygen in the Bessemer converter and in the Tropenas (side-blown) converter, its use in the Austrian L-D (Linz-Donawitz) process of making steel in which oxygen is used throughout the blow and delivered downwards through a vertical pipe, and its application in the decarburisation stage of refining. Information is given on the utilisation of oxygen in electric furnaces for the making of carbon steels and stainless steels. This section concludes with some comment on the problem of air pollution which accompanies the use of oxygen in steel making. The authors refrain from recommending any particular method of overcoming this nuisance.

The second section commences by a theoretical consideration of the reaction between oxygen and carbon and then goes on to inspect its application in the normal blast furnace, the cupola, the low-shaft blast furnace (still an experimental undertaking), and the making of ferro-alloys in the blast furnace. This last application is expected to go further.

The last section of the book deals with the effect of oxygen on flame combustion and the thermal efficiency of heating a charge at high temperature. Its application is primarily to the shortening of the melting-down period after charging scrap. The authors suggest a considerable expansion of this technique in Great Britain.

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The Month's News in Brief

Babcock & Wilcox Ltd. have announced the formation, operative from October 2, of an atomic energy department. This department will be responsible under the direction of the company's chief engineer, Mr. W. F. C. Schaap, for the development, proposition and contract engineering in the atomic energy field. Mr. T. B. Webb has been appointed chief engineer and manager of the new atomic energy department and Mr. W. R. Wootton as assistant manager. The position of chief research engineer, vacated by Mr. T. B. Webb, will be filled by the appointment of Dr. W. B. Carlson, at present assistant to Mr. Webb.

Because of recent rises in ocean freight costs, Borax Consolidated Ltd. have been forced to increase the price of their chemical products by £1 per ton as from October 1. However, the company have announced that, unless exceptional circumstances arise, they intend stabilising these new prices until at least March 31, 1957.

The Osaka Gas Company, Japan, has placed an order for two large carburetted water-gas plants for their Kyoto works with Humphreys & Glasgow Ltd. The installation will have a total daily capacity of 200,000 cu. m. of 470 Btu. gas, i.e. about 7,500,000 cu ft. Heavy oil will normally be used for enrichment, and the plant will help to absorb some of Japan's surplus coke.

Spencer & Partners, who designed and supervised the cathodic-protection system for the Sui-Karachi gas pipeline in Pakistan on behalf of The Sui Gas Transmission Co. Ltd., have been commissioned to design and supervise similar installations for the proposed Sui-Multan gas pipe-line of the Pakistan Industrial Development Corporation.

Simon Engineering (Midlands) Ltd. are to hire out their well-known hydraulic platforms. Fleets of these machines have been established in London, Birmingham and Manchester.

Compoflex Co. Ltd. have moved to 23-25 Northumberland Avenue, London, W.C.2. Tel.: TRAfalgar 7800.

Safety Products Ltd. announce that all communications should be addressed to their new offices at Holmethorpe Avenue, Redhill, Surrey. Tel.: Redhill 4304/5.

Dallow Lambert & Co. Ltd. have moved their London office to 6 Stratton Street, London, W.1. Tel.: GROsvenor 4766. The move will enable a small permanent exhibition of dust control equipment to be installed. Office manager is Mr. A. P. Reeve.

Electrofact Ltd., the British subsidiary company of Electrofact N.V., Amsterdam, has recently been acquired by Hartley Electromotives Ltd. Electrofact will in future be known as the Electrofact Instrumentation Division of Hartley Electromotives Ltd.

The Board of Trade has made an Order confirming a revised scheme for the provision of funds for the Iron and Steel Board, under Section 13 of the Iron and Steel Act, 1953.

Hilger and Watts have asked us to announce that they are the sole U.K. agents for Jarrell-Ash Co. of America. Likewise, Jarrell-Ash are agents for Hilger and Watts in the U.S.A.

Atomics

Britain and Germany are to cooperate on the peaceful uses of atomic energy. An agreement to this effect was signed recently in London, and under its terms the Federal Republic of Germany may obtain, on terms to be agreed, research reactors and the necessary fuel elements, and unclassified information on topics to be agreed concerning the design, construction and operation of these reactors. The Atomic Energy Authority will, wherever possible, provide facilities for training, and the parties to this agreement will help each other to obtain the research quantities of materials needed for their atomic-energy programmes.

Use of Irrathene irradiated polyethylene tape as an insulation by motor repair shops is described in a brochure ("Irrathene Irradiated Polyethylene Tape for Motor Repair Shops") recently issued by the American General Electric Co.'s Chemical Development Department.

Admiral Strauss, chairman of the American Atomic Energy Commission, criticised the Soviet Union's secrecy surrounding its nuclear test programme. The main point of his criticism, which accompanied President Eisenhower's announcement that the Soviet Union had resumed the testing of nuclear weapons on August 24, was its (Soviet Union's) failure to give any assurances, in terms of safety, with respect to the way in which it conducts a nuclear weapons test.

The European Organisation for Nuclear Research has accepted an offer by the Ford Foundation of a £142,850 grant, to be spent over five years, to help in strengthening cooperation in nuclear physics research, primarily with the U.S.A. and other countries not members of the organisation.

What is claimed as the first irradiation laboratory in the British rubber industry has just been completed at the Dunlop Research Centre, Birmingham. Work with a 100-curie source of cobalt 60, obtained from Harwell, is about to start, and later a full source of about 1000 curies will become available.

People

Mr. D. R. Mackie, managing director of Monsanto Chemicals Ltd., announces that, to meet the organisational requirements of the company's development programme, the following appointments took effect from August 1, 1956: **Mr. W. M. Thompson**, director of purchases, to sales director; **Mr. J. S. Brough**, chief engineer, to general manager of production; **Mr. J. S. Hunter**, sales controller, to general manager of development; **Mr. W. E. Hamer**, manager of research department, to general research manager; **Mr. J. M. Keshaw**, project manager, to chief engineer; **Mr. D. C. M. Salt**, sales controller, to general manager of sales; **Mr. G. Dodd**, director and general manager of Monsanto Plastics Ltd., to controller of purchases, Monsanto Chemicals Ltd.; **Mr. E. L. Pixton**, sales controller of Monsanto Chemicals Ltd. and a director of Monsanto Plastics Ltd., is, until further notice, seconded to devote the whole of his time to promoting the present and future marketing interests of Monsanto Plastics Ltd. The appointment is also announced of **Mr. O. W. Murray**, chief construction engineer, to deputy chief engineer.

Mr. E. T. Gill, has joined the staff of the Development and Research Department of The Mond Nickel Co. Ltd., as development officer for constructional alloy steels. He is taking up the position which became vacant when **Mr. L. W. Johnson** was appointed assistant manager of the Department.

Mr. D. A. Bennett, works manager of the Distillers Co.'s plastics group of factories, has been appointed general manager of the International Synthetic Rubber Co., formed by Dunlop in partnership with the Goodyear, Firestone and Michelin com-

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panies in Britain to make general-purpose synthetic rubber on a large scale for the first time in the United Kingdom. (See "Digest", pp. 238-9, September, 1956.)

J. R. Wingfield

D. A. Bennett

Huntington, Heberlein & Co. Ltd. (a subsidiary of Simon-Carves Ltd.) anncunce that **Mr. J. R. Wingfield** has been appointed a director of the company, and that he also retains his position as company secretary.

The following have been appointed to serve as directors of Keith Blackman Ltd.: **Mr. C. J. Atkins**, sales director; **Mr. F. W. Goodge**, contracts director; and **Mr. S. Hudson**, director and London works manager. Simultaneously, **Mr. A. H. Woodley** was appointed sales manager.

The Smithson Research Fund Committee of the Royal Society and the University of Cambridge have awarded the Smithson Research Fellowship to **Dr. Anita I. Bailey**, of Newnham College, Cambridge. Dr. Bailey, who is a graduate of the University of Witwatersrand, South Africa, is to carry out an investigation on the surface energy of some solid materials and of the variations in this quantity which may occur when physical conditions are varied. The research in to be done at the Department of Physical Chemistry, Cambridge University.

Dr. J. Pearson, assistant director of the British Iron and Steel Research Association, will from 1 September, take over charge of the Sheffield laboratories and will have his office at Hoyle Street, Sheffield, 3. He will retain the headship of the Steelmaking Division but will relinquish control of the chemistry Department, for which **Mr. E. W. Voice**, head of the Ironmaking Division, will become responsible. **Mr. R. Mayorcas** will be appointed deputy head of the Steelmaking Division.

P. H. Brind, deputy director of the British Productivity Council resigned the positon on August 31 at his own request. He was succeeded by **Mr. A. J. Speakman. Mr. N. B. Gallagher** was appointed as general secretary of the B.P.C. from August 1 last.

Dr. R. M. Burns, a senior scientific adviser to the Stanford Reseach Institute, has been named recipient of the Acheson Medal of the Electrochemical Society for the biennial year 1956. The medal and a prize of $1000 will be presented to Dr. Burns at a dinner on October 2 at a convention of the society in Cleveland, Ohio. The 1956 award recognises Dr. Burns' work on the corrosion of metals and his long-time participation and leadership in the affairs of the society. The recognition to Dr. Burns is being made in the centennial year of the birth of **Edward G. Acheson**, whose achievements the award honours.

The South African Council for Scientific and Industrial Research has announced the appointment of **Dr. J. P. van Zyl** as its first scientific liaison officer in Germany.

The Council of the British Institute of Management have elected as chairman **Mr. H. Wilmot**, chairman and managing director of Beyer, Peacock & Co. Ltd. Mr. Wilmot succeeds **Mr. H. F. Spencer**, who retires after the customary period of two years. In recognition of his services, Mr. Spencer has been elected a life vice-president of the Institute.

G. A. Dummett *who has been elected to the board of The A.P.V. Co. Ltd.*

Dr. L. L. Marton, of the National Bureau of Standards, has been elected to the Royal Academy of Belgium in recognition of his contributions to science. Dr. Marton will fill the vacancy left by the Dutch physicist, **J. Verschaffelt**, who died last year. He will be the only American physicist among the foreign members of the Academy.

The Board of Trade announce that the President has appointed **Mr. Bernard A. Hopewell** and **Mr. Walter T. Wren** members of the Council of Industrial Design. He has reappointed **Mr. W. J. Worboys** chairman, and **The Lady Sempill, Mrs. Alison Settle, Sir Colin Anderson** and **Mr. J. Cleveland Belle** members on the termination of their existing appointments.

The Council of Sheffield University have appointed **Dr. J. White** to the Dyson Chair of Refractories Technology.

Dr. J. Weiss, Reader in Mechanism of Chemical Reactions, has been appointed to a Professorship of Radiation Chemistry in the Newcastle divison of Durham University.

Among this year's recipients of honorary degrees of Oxford University is **Sir Robert Robinson**, who was until recently Waynflete Professor of Chemistry at Oxford. Sir Robert is a director of Shell Chemical Co. and has a special research laboratory in the Shell laboratories at Egham which were formally opened in May this

Coming Events

The Fifth Factory Equipment Exhibition will be held at Earls Court, London, from April 29 to May 4, 1957. Details may be obtained from Factory Equipment Exhibitions Ltd., 4 Snow Hill, London, E.C.1.

By arrangement with the British Iron and Steel Research Association, the Iron and Steel Institute is organising a Corrosion Meeting to be held at its offices, 4 Grosvenor Gardens, London, S.W.1, on Friday, October 12, 1956. The chair will be taken by Dr. H. H. Burton, president of the Institute, supported by Dr. J. Pearson, assistant director of the Association.

The Second International Congress of Surface Activity will be held in London from April 8-12, 1957.

A Symposium on Microchemistry, under the auspices of the Society for Analytical Chemistry and organised by the Midlands Section and the Microchemistry Group, is to be held in Birmingham over the period August 20 to 27, 1958. Further details will be announced at a later date.

The theme of this year's national conference of the British Institute of Management is "Management—Profits—Living Standards". The conference will be held at Harrogate (October 31 to November 2) and will be opened by the Postmaster-General, Dr. Charles Hill.

The Thirty-eighth National Metal Exposition and Congress of the American Society for Metals will take place in Cleveland, October 8 to 12, 1956.

The Third International Automation Exposition is to be held in the New York Trade Show Building, New York, November 26 to 30, 1956.

The British Nuclear Energy Conference announce a Symposium on "Calder Works Nuclear Power Plant" to be held at the Institution of Civil Engineers, November 22 and 23, 1956. The chairman will be Sir John Cockroft. All communications to The Secretary, A. McDonald, 1-7 Great Chester Street, London, S.W.1.

Standards—Guides for Tomorrow is the theme of the Fifth Annual Meeting of the American Standards Engineers Society to be held at the Hotel Willard, Washington, D.C., from October 3 to 5, 1956.